Educational Communications and Technology:
Issues and Innovations

Laurie O. Campbell
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Perspectives on Digitally-Mediated Team Learning

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Preface

As information continues expanding and occupational knowledge becomes increasingly specialized, the ability to work effectively on diverse teams becomes increasingly vital. The trend towards more robust collaboration, knowledge management, and communication skills is an increasingly central skill for today's students who will become tomorrow's workers in STEM fields. Thus, providing learners with teamwork, collaboration, communication, and problem-solving opportunities across diverse disciplines is becoming a more necessary, but often overlooked, aspect of education in a variety of fields. Further complicating this issue is that such skills are not typically developed via traditional instructional practices. One potential manner to simultaneously address these issues is through revisioning pedagogical practices, transitioning from more passive, teacher-centered to more active, collaborative, student-centered instructional approaches. Considering the unprecedented emphasis on education, both nationally and globally, the ever-escalating needs and the broad implications of establishing research-based evidence and guidelines for promoting innovative pedagogical practices that support team-based learning are increasingly critical to achieve success.

Solving multifaceted problems to address societal concerns supports the need to build teams that can solve complex issues. In that vein, various disciplines can support team dynamics through digitally mediated team learning (DMTL). DMTL is positioned within known bodies of learning science literature including but not limited to: (a) Computer-Supported Collaborative Learning (CSCL), (b) Computer-Mediated Communication (CMC), (c) Team-Based Learning (TBL), (d) Case-Based Collaborative Learning (CBCL), (e) Collaborative Learning (CL), (f) Cooperative Learning (CopL), (g) Problem-Based Learning (PBL), (h) Learning Analytics (LA), and (i) Educational Data Mining (EDM). Further, DMTL embraces technological applications that afford learners opportunities to solve problems, develop ideas, and co-construct learning outcomes, either asynchronously and synchronously, whether students are in the same room or across the world, providing for ease of communication, documentation of process, and co-construction of solutions and idea.

DMTL-focused pedagogical approaches can leverage advancing learning technologies toward attaining great potential to increase educational efficacy, scalability, and diversity across fields and levels. The activities that support team design, group problem solving, and project collaboration have always been a prominent and even defining attribute of effective pedagogy. Especially in the last two decades and into the foreseeable future, team design skills are receiving increasing importance as the complexity of knowledge acquisition, retention, and transfer marches ever forward. The rising tide of complexity necessitates future graduates at all levels and across numerous fields to function effectively as disciplinary specialists who work together closely and frequently during most phases of product development and research. The need and benefit for learners to become immersed in collaborative learning activities have been highlighted, in order to elevate their needed proficiency in team-based skills. Thus, the priority for advancing forward-looking educational technologies demonstrating the most significant potential to advance team-based instruction is vital and broadly impacting across fields as learning partners, group project teams, and collaborative design projects rely heavily on team-based and collaborative learning. Research in DMTL is especially timely due to the recent proliferation of virtual collaboration technologies ranging from laptops and other mobile devices, tablets, Wi-Fi-enabled networking, sensors, cameras, and embedded devices.

This book emerged as a response to the need to support transactional communication leading to transformative learning and, more specifically, the National Science Foundation *Principles for the Design of Digital Science, Technology, Engineering, and Mathematics (STEM) Learning Environments* awarded grant [DCL-NSF 18-017], grant DRL-1825007 titled *Synthesis and Design Workshop: Digitally-Mediated Team Learning* resulted from a collaborative effort of the editors to address these emerging pedagogical needs. The workshop that took place during the spring of 2019, at the University of Central Florida included 88 researchers, educators, and practitioners from across the United States. Participants explored effective and scalable team-based learning in digital environments and projected how varying aspects of the field would morph and grow in the subsequent 1, 3, and 5 years. Out of a desire to highlight current work in the field of those practicing aspects of DMTL, the creation of this book was initiated. Thus, this book will explore technology-supported pedagogical approaches that facilitate teamwork, collaboration, communication, and problem-solving opportunities in diverse disciplines and is motivated by expanding the learning science research base regarding how constructivist pedagogical principles and strategies, including structured, collaborative, active, contextual, and engaging instructional settings, can support foundational instruction and improve student interest and achievement.

This book showcases full-length manuscripts advancing transformative pedagogical approaches for technology-enhanced team learning within varied disciplines and includes contributions from interdisciplinary researchers, developers, and educators focused on the facilitation of adaptable digital environments for highly effective, rewarding, and scalable team-based and collaborative learning. More specifically, this book highlights theoretical works and empirical studies that explore ways in which technology-enabled pedagogical principles and practices facilitate student interest, while also providing an exploration of logistical factors associated with revisioning pedagogical approaches and informing the design of instructional settings in various subject areas in K-12 and higher education. Further, these works will assist administrators, instructors, and course developers in creating effective learning environments to best meet the needs of all students, while simultaneously addressing technology-supported pedagogical and logistical challenges commonly seen in K-12 and higher education.

Book Sections

At its core, this book is focused on advancing knowledge on technology-enabled team and collaborative learning. The chapters within will inform immediate and future research and practice related to: (a) harnessing learning analytics for optimal team learning; (b) innovative pedagogical approaches utilizing technology-enabled team and collaborative learning; (c) traditional and emerging technological applications to support and promote team-based learning; and (d) logistical and other issues for broadening participation and presence in team learning. The explorations and outcomes related to these topics are of interest to researchers, educators, and industry as they could inform the creation of beneficial, scalable, sustainable, and transportable educational solutions for developing team learning and interactive learning environments through digital means. This book contributes to future cross-networking and co-constructing among the experts in the aforementioned fields as they continue to investigate aspects of digitally mediated team development to benefit the associated researchers, educators, and practitioners.

The book is structured around the following parts:

1. **Pedagogical Perspectives in Digitally Mediated Team Learning**
   The ability to facilitate DMTL-focused approaches across levels and disciplines is becoming increasingly important. While technological tools that support varied pedagogical practices that enable effective DMTL-focused teaching and learning environments are becoming increasingly common and useful, it is critical that such tools be accompanied by appropriate pedagogical approaches that address the myriad of issues associated with effectively facilitating DTML-based environments and support such approaches as team design, group problem solving, and project collaboration. The four chapters in this part explore various aspects of DMTL-rich teaching and learning environments by highlighting instructional approaches to address a variety of pedagogical issues typically associated with team learning, such as (a) instructor roles in real-time team-based instructional settings, (b) managing accountability in team-based settings, (c) aligning tools with appropriate pedagogical approaches, and (d) team-based learning at various educational levels, among others.
2. **Tools for Facilitating Digitally Mediated Team Learning**
   The increasing ubiquity of technology in almost every aspect of our everyday lives as well as the continually increasing usability and advanced functionality of

both traditional and emerging technologies opens the doors for a myriad of approaches to the numerous pedagogical, logistical, and social issues associated with team-based and collaborative learning. However, the integration of these tools into the teaching and learning environment is not one of merely "plug-and-play." Thus, in this part, the three chapters provide guidance for the integration of traditional and emerging technological applications and address a number of ways in which such tools can allow for more active, engaging, and communicative teaching and team-based learning environments, as well as ways in which tools can support instructor professional development for the integration of both traditional and emerging technological tools to support DMTL-based pedagogical approaches in STEM curricula.

3. **Analytics and Social Perspectives of Digitally Mediated Team Learning**
   Research regarding the formation and function of teams continues to grow in the teaching and learning literature. Learning analytics provide rich information for making informed decisions regarding learning. In technology-mediated environments, analytics can support understanding for instructors and team members of how teams are functioning. The data points generated in learning may optimize the individual and team learning experience. Likewise, social presence, a construct that has evolved to mean the way individuals view social interactions and others, has been identified as a contributor to learner satisfaction, performance, and achievement. In this part, social presence has been explored to include definitions, tools, and actions that will build rapport and trust among learners in online environments.

In conclusion, we are pleased to be able to bring you this book on a variety of issues associated with DMTL. In these pages, you will find thoughtful and well-written chapters that can be used to improve practice while informing both current and future research.

Respectfully,

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Part I
Pedagogical Perspectives in Digitally-Mediated Team Learning

Aligning Teacher Facilitation Tools with Pedagogies in a Real-Time Environment for Mathematics Team Learning

Leslie Bondaryk and Chad Dorsey

Abstract Digitally facilitated team-based classrooms require a rich set of tools to support teacher noticing and classroom orchestration. While only limited research has been conducted on effective tools for teachers, we have been able to construct a teacher dashboard along with feedback and content customization features that allow middle-school mathematics teachers to effectively teach team-organized, digitally facilitated classes in an in-person, hybrid, or online classroom environment. Two key features of the digital environment include a dashboard allowing the instructor to monitor and inspect all student artifacts in real time and a workspace allowing teachers to generate and publish content of their own. We describe the functionality of the purpose-built STEM collaborative classroom system and the particular ways it facilitates effective classroom orchestration and noticing.

Teaching with Technology-Enabled, Problem-Based Curricula

Teaching a technology-enabled, problem-based curriculum is a balancing act between keen student observation, prompt just-in-time contextual problem feedback, and technical support of the software platform. Teachers need to aid students in acquiring facility not only with the content and practices of the domain but also with the mediating technology-based tools. In such a scenario, teachers and students share more responsibility for the learning process than in a teacher-centered or direct instruction environment (Bransford et al., 1999; Lampert, 2001). Teachers in software-enabled scenarios assume an increased burden to notice and evolve the disciplinary content of students' work (Franke et al., 2001; Schifter, 2005). Student work in teams within a platform magnifies this challenge, as the flow of ideas between students and the path along which the group work evolves is part of the work of constructing the team's joint problem space (Roschelle & Teasley, 1995;

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Stahl, 2006) and demand teacher coaching and evaluation. In live classrooms unmediated by digital technology, much of this interaction is ephemeral, lost to untracked conversations, or locked in individual students' notebooks. In other cases, the interactions veer off-topic entirely (Barron, 2003). Effective teacher noticing depends strongly on teacher access to student inscriptions (Sherin et al., 2011). Thus, supporting such noticing in technology-based scenarios, where the majority of students' work occurs on screens, demands new types of digital support features (Walkoe et al., 2017).

Classroom Orchestration

Teachers in a hybrid or purely digital setting depend broadly on digital systems for access to facets of learners' activity that stretch beyond basic measures of progress. A digital platform tool must be capable of communicating the class "script" to the students and must allow the teacher to track progress against that script (Martinez-Maldonado et al., 2015). Teachers must be able to see and comment on their students' learning artifacts in ways that are easily consumable by students. They must also have access to both synchronous and asynchronous methods of communication with multiple class members such that they can provide clear written expectations and responses across reliable sequences of activity, discussion, and reflection (Amarasinghe et al., 2020; Tinker, 2001).

Teachers should be able to communicate effectively in the subject matter domain in written form, including through digital means. Preferably, this communication should employ an identical inscriptional toolset to that used by students, to allow for equivalent abilities to facilitate and communicate about the content. In a collaborative classroom, teachers need to monitor the progress of both individual students and groups. Additionally, teachers need classroom orchestration tools that can help them understand the progress of the class as a whole so they can efficiently identify commonalities in student understanding, customize curriculum, and moderate group dynamics (Dillenbourg et al., 2012; Matuk et al., 2015). A classroom system for mediating collaborative learning should help teachers to orchestrate learning, including summaries of class understanding, and to conduct group facilitation activities. Protocols for these activities in the physical classroom often have well-established, paper-based patterns. However, they may or may not occur identically in the digitally mediated classroom. Finally, these digital tools must support instructors in evaluating students' overall progress and in assessing how the curriculum materials, digital platform, and student interactions support or hinder the progress of individuals, teams, and the full class.

In order to facilitate a documented trail of student inscriptions that benefit both student learning and teacher noticing, the Concord Consortium has developed a collaborative mathematics platform that allows students to work with digital mathematics tools in groups. The Collaborative Learner User Environment (CLUE) is designed to provide the curriculum (Dillenbourg et al., 2012 "script"), the student artifacts, and the teacher commentary all in the same format via the same digital tools. This set of common affordances allows students to observe, publish, and borrow artifacts directly from shared peer work, instructor-provided materials and exemplars, and the curriculum materials themselves (Dorsey & Bondaryk, 2019; Sharma & Edson, 2020). While the system is an equalizer in the classroom, encouraging all students to participate and validate their contributions among their peers (Sharma & Edson, 2020), teaching with this real-time collaborative document system presents a number of unique challenges. We designed a set of platform affordances that support teacher noticing and interaction with individuals, groups, and the whole class, teacher evaluation of work, and teacher participation in the collective process. The platform offers an unprecedented window into how groups of learners generate, borrow, amend, and share artifacts in a learning environment in which the goal is to collectively discover, define, and refine mathematical principles. This information is invaluable to teachers seeking to scaffold their students. The dense, rich nature of possible feedback requires specific affordances to allow teachers to make sense of student inscriptions and interactions and capitalize on them for the benefit of problem-based instructional techniques.

Classroom Script and Monitoring

To date, classes using this platform have been taught in the context of the *Connected Mathematics Project* (CMP) curriculum (Lappan et al,. 1998, 2006, 2014). This curriculum was originally designed for paper and pencil in a live classroom. Instructors both participate in and assess success in the paper curriculum through observation of physical group documents and individual student notebooks of mathematical inscriptions. Within the digital system, we needed to provide equivalent or enhanced opportunities for the same type and quality of interactions. Further, in the digital system, inscriptions are copied from one student's document to another to evolve ideas, allow students to see tangible artifacts and evidence that their ideas are valued by their peers, and enhance the collective understanding. Teachers can capitalize on this to follow and encourage the temporal joint problem space evolution (Sarmiento-Klapper, 2009), providing benefits to both the students and the teacher (Edson & The Concord Consortium, 2019).

The CMP problem-based curriculum is a good test of the CLUE Platform's collaborative teacher supports because of both the consistency of the program's curricular sequence within each unit and the rigorous teacher training that is part of the program. These commonalities allow us to return information to teachers via a dashboard in a consistent—and, therefore, learnable—format. Teachers of this curriculum are active participants in the evolution of ideas in groups, actively responding to individual- and group-developed concepts and evolving classroom learning needs. They must introduce problem-based activities while connecting them to previous learning and must continually track and advance work across the classroom. During class and teacher preparation sessions, teachers must be able to review student work while preparing for unit summaries or setting up instruction for the following day or beyond. During this review teachers identify student exemplars that may be useful for group conversation and search for concepts taken up and/or missed by individuals, groups, or the entire class. At regular intervals, teachers must orchestrate whole-class summary discussions in which they draw examples from student strategies and group work, sequencing them to evoke the embedded mathematical understandings and elicit group realizations about how these understandings connect the work together and tie it to both prior and future knowledge (Bieda et al., 2020).

Student Experience and Workflow

To understand the teacher affordances in the mathematical platform, it is first important to understand the student experience inside the team-based learning environment. The system groups students in teams of up to four students. Students have access to a variety of domain-appropriate tools (e.g., graphs, tables, text, images, and drawings), which they can use in ad hoc and self-selected ways. A series of "tiles" that the student can freely rearrange, update, and delete in their documents contain tools for writing text, manipulating geometric figures, creating graphs, and more. Students construct documents in CLUE using these tools to create responses to questions posed by the teacher and the curriculum materials. The CMP curriculum is built into the platform, and the published content uses the same set of platform tools. This pattern enables students to copy items directly from the curriculum to incorporate into responses. The ability to begin with content that can be freely transformed by students, in tandem with the team-oriented and open-ended nature of the problems themselves, deliberately creates opportunities for individual students or groups to arrive at alternative approaches to problem solutions.

Class work typically follows a pattern that involves members working individually, followed by a reveal of individual work to group members, and then to the whole class, although some teachers prefer to have groups begin with student workspaces immediately shared within groups; the platform supports either approach. Documents allow students to copy granular pieces from each other's work or from the curriculum by dragging and dropping tiles or subsets of content, a feature designed to encourage cross-pollination of solutions and ideas. The overall effect of this interaction pattern is to elevate student contributions to an equivalent level of importance to those from the original problem. Studies of the Scratch community show that users can learn by looking at and borrowing from other users' creations (Resnick et al., 2009). In those cases, however, the interactions are typically unidirectional, with feedback tending to consist of the "giving of credit" to originators of the source project (Monroy-Hernández & Hill, 2010). In contrast, we designed the CLUE interface explicitly to encourage learners to model for one another and learn from one another, using an always-available WYSIWIS (Stefik et al., 1987) shared desktop and structured intermediate work products designed to promote iterative refinement (Dorsey & Bondaryk, 2019).

This work pattern also helps students overcome confusion over how to begin a problem, especially in classrooms where the culture and social contract acclimate students to holding each other accountable for the overall classroom learning and for contribution to equal shares of the assignment work. Once students have achieved some success in their groups, teachers sometimes encourage students to publish their work so it can be viewed by the whole class. Each of these real-time document instances, whether shared within small groups or across the full class, have the same "borrow-and-reuse" functionality. Students are also encouraged to journal in a "learning log," another set of cross-referenced documents that sport the same toolset but are available persistently across curriculum units, encouraging students to build upon previous solutions and reflect on their learning over time. Such documents eventually even become founts of information for students, which they can use to "borrow from themselves" to construct summaries of understanding or bridge to new work from past understandings.

One of the interesting opportunities this pattern of progressive refinement affords is the opportunity for students to do the same kind of peer instruction previously instrumented with clicker systems. In such clicker systems, students typically answer a question individually, discuss the question with their peers, and answer the question a second time as a group (Barth-Cohen et al., 2016; Mazur, 1997). A prime value such systems offer instructors is the manner in which they provide real-time recorded feedback about student understanding and reveal its progressive evolution. In similar ways, the CLUE collaborative platform can provide invaluable, ongoing monitoring of peer inscriptional evolution and student understanding.

Affordances for Class Orchestration

Teacher Dashboard

To facilitate monitoring of this dynamic, multi-team system, we needed to create a robust set of teacher tools that would enable teachers to keep pace with the fast-moving groups of students as they swapped and shared ideas and inscriptions that offered benefits above and beyond what could be done by walking around a classroom with students working on paper. While a number of projects have created classroom dashboards to monitor students' individual learning progress (Verbert et al., 2013), very few allow teachers to monitor the state of collaboration within small groups (Martinez-Maldonado et al., 2012) or with a sophisticated set of STEM-based live artifacts. The platform described here includes a teacher dashboard that specifically supports monitoring of progress on the CMP curricular sequence and provides actionable insight and an interface to digitally conduct the orchestration required by the curriculum.

For teachers beginning a particular problem in the curriculum, the starting point is their teacher dashboard, a display that shows all student documents depicted in their group formations (Fig. 1). For reasons of screen real estate, we have limited the view to six groups of four students each; in classes with more than six groups, teachers can access additional groups by scrolling the screen downwards or upwards.

This view supports a rich set of observations. The nature of the mathematical content, particularly in a seventh-grade mathematics curriculum unit focused heavily on geometric transformations and linear data manipulation, makes it very easy for a teacher to tell which students are progressing predictably on a given problem and which are pursuing alternate or off-topic solution paths, even using these thumbnail-sized views of the student artifacts. For example, the problem shown in Fig. 1 involves shapes that tile into similar larger versions of themselves. (Student work from Group 3 in the upper right corner and Groups 4 and 5 on the lower row shows a set of shapes supplied with the curriculum.) Some students have only progressed as far as copying the supplied set from the curriculum, while others have used these shapes, or some of their own, to create tiled fields of shapes within their graphs. Some have not started (evidenced by documents displaying only horizontal document separator bars as in Groups 2 and 3). Several students are documenting their work (text areas) and one student is absent (the white square in Group 5).

This dashboard view also allows teachers to determine the progress of students within each problem itself. The circle icons on the far right indicate the typical sections in this curriculum. Next to each section icon is a count of the number of students who have entered at least one content tile of any sort in that section.

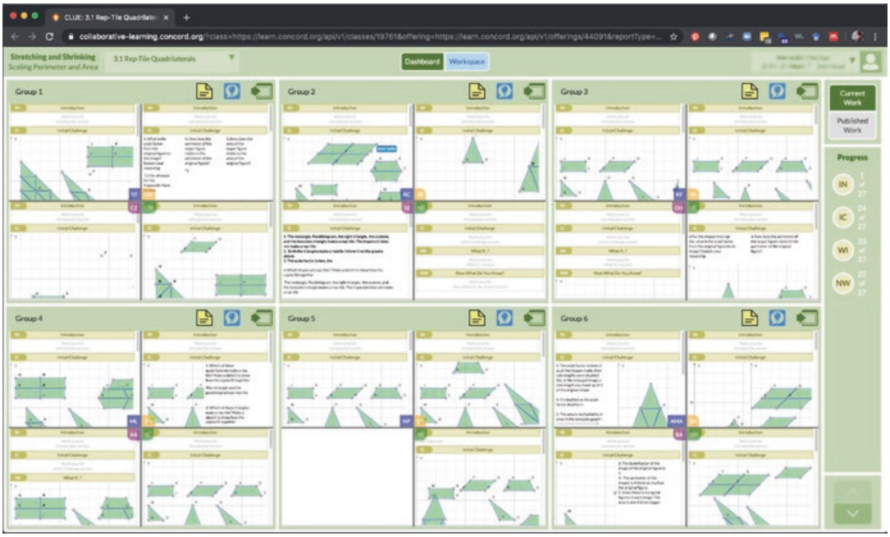

Fig. 1 The Collaborative Learner User Environment Dashboard, showing 24 real-time student documents in progress and teacher intervention tools

Clicking on these icons scrolls all student documents to that section, allowing the teacher to compare like parts of the assignment and determine when it is time to intervene, gather students for discussion, or encourage the class to continue to the next section. This functionality offers particular value both for teachers preparing for in-person class sections and for teachers teaching remotely, since remote or asynchronous scenarios often make it difficult to determine when a class is ready for discussion or prepared to transition to a new topic.

It is also possible for teachers to see how many of their students have published work to the class. This alternative view represents the final transition of sharing work and allows teachers both to check the completion and sharing of students and to “star” work pieces for easy reference in the future.

If teachers wish to access a more detailed view of an individual student’s work, they can click on that student’s pane, which expands the selected student’s work to fill the group’s frame. Additionally, teachers can also switch to a workspace view that mirrors the group view of students, with the addition of a content tab for student workspaces (Fig. 2). This allows teachers the ability to see a very detailed view of each group and to create reference documents by borrowing student content (using the same, copy and paste mechanisms that work for all users in all documents).

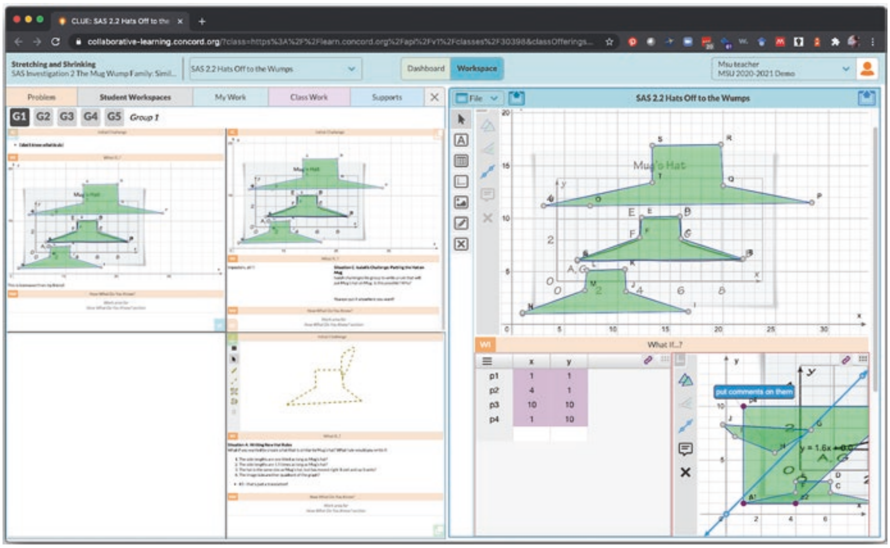

Fig. 2 The teacher workspace has the same functionality as the student workspace (right pane), but also includes a tab in the content section (left pane) displaying the group views of all student workspaces, just as the dashboard does

Teacher Interventions: Notes

Teachers using the CLUE platform have a variety of options for interacting with their students, all of which speak to the noticing and orchestration themes of collaborative teaching. In the dashboard view, yellow "sticky note" icons are associated with each group. These allow the teacher to instantly send a note either to the whole group or to an individual student. Annotations persist in the student workspaces (Fig. 3) and can be used for anything from motivational feedback to classroom prompts. One teacher in a spring 2020 class test used these to provide slightly different question prompts to each student in each group. As students worked on the individualized prompts, then shared their work with their group mates, they discovered that each was working on a slightly different form of a related problem, evoking a more nuanced group conversation and interaction about the nature of the problem and comparison of alternate solutions.

Among the 5 teachers in 23 classrooms who participated in trials during the spring and fall of 2020, in various in-person, hybrid, and remote learning environments, we saw a broad variety of uses of notes. Some teachers used them to engage students in class participation, or to facilitate turn taking during class-wide discussions. For example:

- "Raise your left hand when you see this!"
- "Group 21!!!!! It's finally your turn!!! Hiiiiiii!!!!! :-)"
- Other teachers included motivational feedback to students:

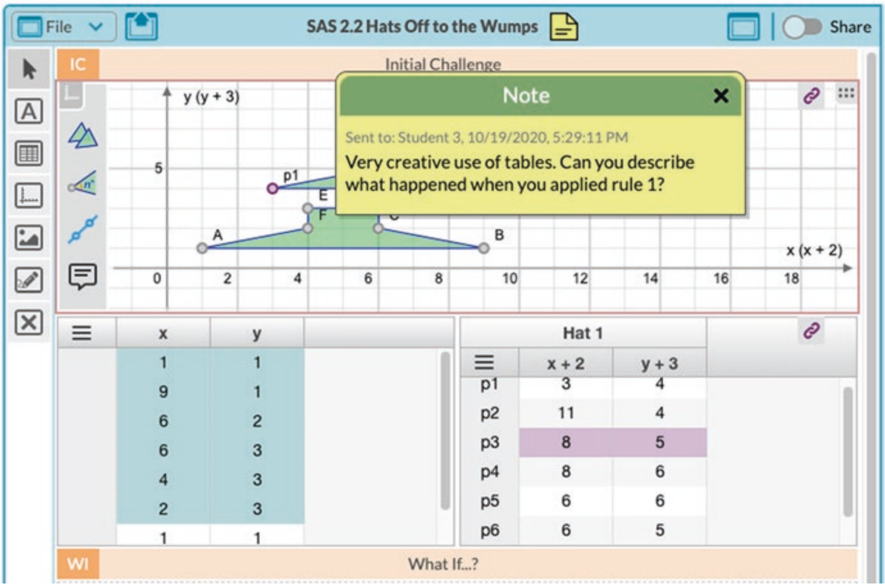

Fig. 3 Sticky note display for teacher-to-student commenting and feedback

- “Love the tessellation.”
- “I’m sorry to hear you hate math. I hope we can find some things you like about it this year.”

Teacher Interventions: Summarizing Student Work

Teachers also produce content in the platform. Each teacher has access to his or her own document workspace with all the same inscriptional tools, as shown in Fig. 2. Teachers are able to publish documents to the Class Work collection, which is useful for making summaries of student strategies and publishing them for class discussion and reuse. Teachers have used this functionality both for these approaches and simply to display individual examples of student work anonymously for class discussion. Teachers in classroom tests published and shared student work for a variety of purposes and instructional strategies. Some displayed documents from the collection on a projected view of the whiteboard (Edson & Concord Consortium, 2020), while others recommended that students end class by publishing their documents or writing in their learning logs. Still others created aggregated student strategy documents and published them as teacher summaries.

Teacher Interventions: Curriculum Extensions

Teachers also have access to a second mode of publishing unique to their role. The CMP curriculum includes curriculum “supports,” which are prompts and extensions to the curriculum that appear on a Supports tab in the content section of the digital platform. Teachers can publish their own supports—these can be as simple as a text prompt, take the form of annotations similar to the sticky notes, or assume forms as complex as an entire entry in the core curriculum. Publishing teacher supports to the class allows teachers to modify and extend the content using a tool set rich enough to allow them to express any required content for the course in a way that makes use of tools with which they and their students are already familiar. This allows teachers to have full agency in the development and customization of the curriculum, which is essential in any kind of digital system. The customizations can be used to engage students in ways that reflect the local population, skill level, or other needs (Dillenbourg et al., 2012; Warwick et al., 2020). Teacher supports, like the published curriculum, also reinforce correct software usage, or can organically suggest ways in which students can extend their facility with the software.

In classroom trials, teachers published a variety of supports and sometimes class worksheets for different classroom purposes. We saw one or more examples of each of the following types of teacher documents:

- Answer keys to challenging problems.
- Answer keys that required a high degree of graphing support, in which case the information was easier to create and convey with digital inscriptional tools.
- Additional or extended curriculum challenges.
- Directions to students about curriculum assignments.

In a class test in fall 2020, teachers created their own versions of the eighth-grade mathematics curriculum by using only teacher supports, as the core curriculum had not yet been translated to digital format. Since the same tools are available to teachers and students as those needed to create the curriculum, it is possible for a teacher to use their own agency to create any curriculum they desire.

Teacher Training and Workflow

Teachers received both live and video training on the use of the CLUE teacher tools in the CMP curriculum and documentation in the form of a companion guide with text and videos about software features. The teacher dashboard and teacher workspace/publishing capabilities were introduced in a third year of use of the platform in CMP classes, in response to requests from teachers during the first 2 years. Although we designed features in response to particular requests, some of our research questions had to do with examining what use teachers would make of the tools without instruction. To this end, teacher training served primarily as an introduction to the location and functionality of the software, without particular prompting to use features for a specific purpose. As we watch both teachers and students interact with the software, we will continue to evolve tools to help teachers find and use them.

To date, teachers have primarily followed a classroom instructional sequence developed and taught during teacher training for the CMP curriculum. Teachers introduce units, ask students to work in groups and share their work with teammates either immediately or after some time working alone, and allow individuals and groups to evolve artifacts. By design, the platform records all actions students and teachers take as they develop documents or problem solutions and tracks actions on and provenance of copied elements. While these data hold interesting stories about social dynamics and influencers among students, they also provide fuel for teachers' actions. For example, the ability to examine student documents in real time through the dashboard can prompt an instructor to coach students in established collaboration patterns such as reminding students to discuss and share their processes or establishing class norms around asking peers before teachers when problem solving (Campe et al., 2020).

We have seen teachers using access to student artifacts not only during classroom instruction but also during preparation time before and after class. In the initial trials, teachers have reported that the system helps them know when to move on to the next topic or when to provide additional coverage.

System Software Architecture

It is worth describing at a high level the way that the CLUE architecture is constructed (Fig. 4). In order to make student documents available in real time to teachers and peers, the platform needs to be able to display student documents quickly to those who should have access to them and safeguard them from those who should not. The CLUE user interface for teachers and students is accessed through the Concord Consortium's STEM Resource Finder, which is used to register users and provides the scope of allowable document viewing and sharing. Students and teachers can create and retrieve files associated with a user account and publish their work securely for sharing only with others in their class. Having all documents in the system authorized by user and by class ensures the right people have access and

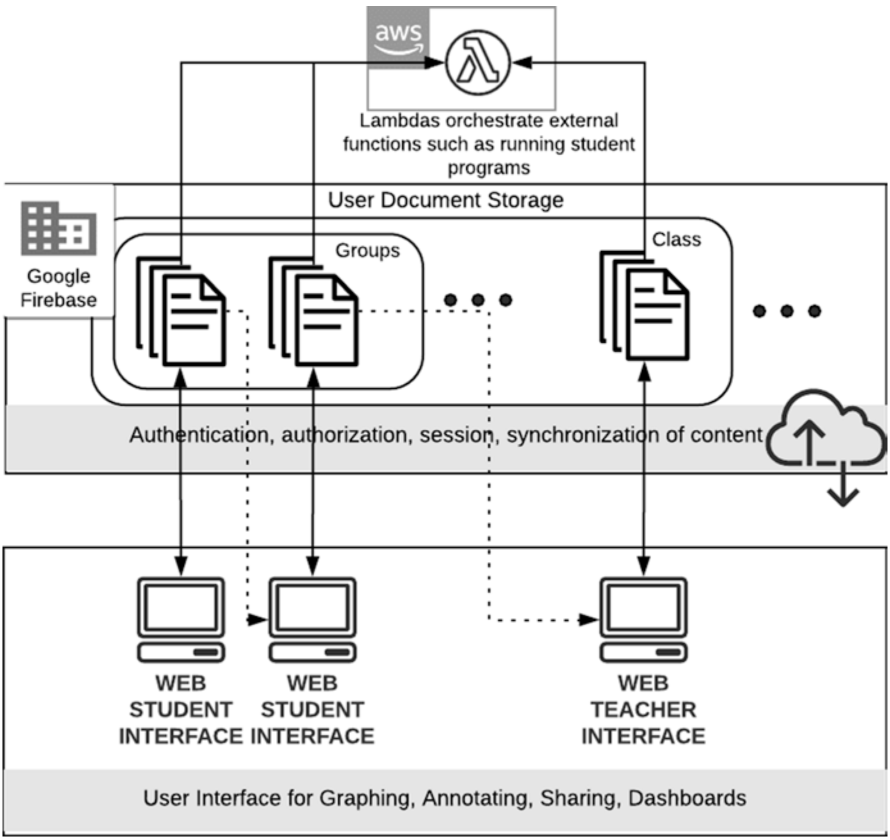

Fig. 4 CLUE documents are stored on the server in a way that reveals them only to members of their class, and which allows small incremental changes to be propagated to anyone viewing a document at that moment

others will not be able to view the work, making it compliant with various security requirements prevalent in most school environments.

Users granted access to any class through the CLUE interface can create and share documents. Documents are updated in a granular and sequential manner so that only the latest changes need to be propagated to any other user who might be viewing the document. Documents may be viewed by multiple users, ranging anywhere from an individual user up to the total number of students and teachers in a class for documents that have been published to the Class Work section. This incremental update strategy also allows us to record a full script of student and teacher actions for research purposes. As a result, we know the series of steps any student takes on their journey to construct a mathematical response and the ways in which students have borrowed from or contributed to their peers' work in great detail.

Summary and Extensions

We have described a novel collaborative STEM platform and mathematics classroom implementation that is specifically designed to address patterns of collaboration and classroom orchestration. Our platform allows us to study how teachers can monitor the small group co-construction processes made apparent through artifact creation and modification, track when and how teachers choose to intervene, and assess the impact of those interventions on the further evolution of the shared artifact. It holds significant promise as a technology-mediated teacher noticing system (Walkoe et al., 2017).

Two key features of the environment include a dashboard, with the ability for the instructor to monitor and inspect all student artifacts in real time, and a workspace, in which teachers can aggregate and share student work and generate and publish content of their own. The teacher dashboard provides not only a form of oversight but also a place from which to support teacher-generated just-in-time interventions, facilitate teachers' preparation of future lessons, and support teachers' reflection on students' collaborative work within the physical or remote classroom.

Educational Strategies

The CLUE system's collaborative and teacher review features enable a variety of rich teaching strategies. Real-time sharing and reuse allows teachers to offer a set of related but distinct questions to a group, allowing groups to work on multiple different methods of evolving the same information. The progressive reveal of information to the group and then to the class gives teachers a way to scaffold these methods and allows students to share their strategies in an organic flow with the material and the system. CLUE's publishing features also enable an enhanced version of the "poster review" that would typically be conducted while summarizing and reviewing groups' learning within a unit in CMP and many other curricula. This review can now easily take place within the platform, either by having students publish contributions to the class workspace or by teacher inclusion of various elements of students' work within generalized class summary documents distributed to the class. CLUE's Class Work and Teacher Support views allow such documents to progress from initial status as ephemeral summaries with no attribution or long-term context to use as a reviewable knowledge-building touchstone students can return to when they like and reuse as the class moves to more sophisticated concepts.

Real-time reviewing features within the platform allow the teacher to intervene with more frequency and at more auspicious moments than typical live classrooms allow, and make such contextualized intervention possible for the first time in most asynchronous or remote classrooms. One teacher in our class testing reported being "able to multiply [herself]" (Edson & Concord Consortium, 2020) because she could be sitting with one group of students discussing their work live and still keep an eye on the activities of all other class members by glancing at her dashboard. This live, bird's-eye view of documents allows an experienced teacher to see whether students are progressing or need help and affords a variety of different intervention methods facilitated by a broad choice of tools: instant notes to a student or a group for more unobtrusive prompts, published Teacher Support documents for clarifying misconceptions and providing reusable document components to the larger group or class, or live interventions for scenarios which merit direct conversation.

Domain Extensions

The system's many affordances, including granular and detailed information about students' journey to construct the joint problem space, provide opportunities to return information to teachers, in the process prompting them to more effective noticing and classroom orchestration patterns. Creating new opportunities for team evolution domains is merely a matter of adding new tools to the suite. We have already created one offshoot of the CLUE system, called Dataflow (Bondaryk et al., 2021), which adds a suite of programming and sensor detection tools to the student STEM inscriptional tools. We look forward to extending CLUE further in other STEM disciplines and finding new ways to surface the available data about student and teacher use for research and other educational benefits.

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Cultivating and Leveraging Continuous Accountability Through Mundane Infrastructures for Critical Thinking

John M. Carroll, Guillermo Romera Rodriguez, Na Li, and Chun-Hua Tsai

Abstract Technology-enabled collaborative learning had been shown to be useful for improving student cognitive performance, promoting social interaction, and positive learning behavior. In this chapter, a utility to manage the logistics of group learning was explored to support collaborative learning and leverage a sense of accountability among group members. In particular, this chapter discusses efforts to (a) develop critical thinking as a general framework for classroom discourse, (b) appropriate infrastructures to support real-time/routine debate and other critical discussion and writing, and (c) develop computer support for group formation and management inclusive of peer evaluation. Based on the findings of this case study, an approach based on critical and dialectical thinking is suggested where students can take an active role in their own learning by creating and modifying their own perspectives.

Introduction

Engaged learners do better, but engagement is not a single thing. In collaborative learning, one source of engagement is accountability to group outcomes, the belief that one's active participation matters. One goal in designing educational tools and activities to support collaborative learning is to cultivate, develop, and leverage a sense of accountability in group members. In this chapter, we reflect on our own efforts to create and support group-based critical thinking activities that integrate and leverage debate in postsecondary classes. Such activities naturally engage

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meaning making and accountability; groups of learners build facts, claims, and anticipated rebuttals into arguments, while other groups are building counterarguments. Participants are continually reminded of their own contributions, and those of their teammates and of members of other groups.

The chapter focuses on our efforts to (1) develop critical thinking as a general framework for classroom discourse, (2) appropriate mundane infrastructures to support real time/routine debate and other critical discussion and writing, and (3) develop computer support for group formation and management, including management of peer evaluation. We leverage existing literature on collaborative learning, especially on dialectical constructivist learning as background and foundation for our chapter.

Critical Thinking as a Classroom Discourse

To explore how critical thinking activities can be configured to evoke accountability in team members, we have developed courses around debate and critical discussion at Pennsylvania State University. For example, a freshman seminar in Information Technology focused on reading and deconstructing authoritative but argumentative popular books, such as Carr's "The Shallows" or Michel and Aiden's "Uncharted," and a Ph.D. core course focused on identifying claims and counterclaims that constitute foundational theories. These activities were implemented as learning jigsaws to cultivate and leverage public accountability in the class. In other words, engaging in collaborative activities helps hold students accountable for their work as they are supposed to take responsibility for their part in a group project. Further, students were engaged by these dialectical constructivist activities and sometimes identified dialectical analysis as a skill they had encountered for the first time.

Online Debates as Learning Activities and Learning Objects

We have reappropriated various tools to support this approach in the previously mentioned courses. We chose these mundane platforms because they are straightforward to use and are useful to support students' collaborative discussion and dialectical constructivist activities.

For example, we adapted the Q/A system Piazza as an interactive debate platform and then developed our tool, Critical Thinker, based on that experience. Both Piazza and Critical Thinker could easily allow people to build question–answer discourses, contributing to establishing dialectical activities, and support students' critical thinking. We appropriated the online debate system Kialo as a platform. Kialo is similar to Piazza; the platform is set up more as a social network for debating. Its management and accessibility are greater than both Piazza and Critical Thinker and are more robust than Critical Thinker (no longer maintained), but weaker as a pedagogical tool. More recently, we have engaged the wiki functionality of Canvas for student debate and deconstruction, and more generally, for argumentative student writing. Students publishing short position papers to the class can be a quick starter for accountable class discussions. In this chapter, we will discuss these tools in depth by comparing their strengths and weaknesses.

Collaborative Learning as Scalable

Most of our classroom studies were conducted in relatively small classes (16–25 students). However, classes are often larger than this, and indeed, these larger classes often incorporate no group learning. Our hypothesis is that if collaborative learning was easier to manage than traditional isolated-learner models, then faculty would be more likely to adopt collaborative approaches. If group formation and management were just easier for faculty, and peer evaluation well-defined and easy to learn from for the students, perhaps collaborative learning practices would be more widely adopted. We have developed a utility to manage logistics of group learning designs, including iterative assignment of students to small groups (that is, students participate in several different groups in the course of a semester) and management of peer review for group products (including automated appeals resolution). A single case study was carried out in fall 2018 and was encouraging. We are continuing to refine and extend our software and enlist more faculty. In the next three sections, we develop (a) motivations for considering critical thinking as a general framework for classroom discourse, (b) describe how we appropriated mundane computational infrastructures to support routine debate and critical discussion and writing in classes, and (c) analyze and develop computer support for challenges of group formation and management, including management of peer evaluation, that can be obstacles to faculty adoption of collaborative learning.

Critical Thinking and Dialectical Constructivism

Critical thinking is an important skill that students need to acquire, as it facilitates synthesis of multiple ideas, making logical deductions, and becoming capable problem solvers. This section synthesizes existing literature review regarding pedagogical practices that support critical thinking and how these can aid students in improving their critical thinking abilities through engaging them in meaningful dialectical learning activities.

Critical thinking is a higher level of cognitive ability that enables people to analyze, synthesize, and evaluate information (Duron et al., 2006). More than merely remembering knowledge and applying it, critical thinking involves questioning knowledge and its applicability to given circumstances, identifying key issues, claims, and empirical evidence that bear on them, and synthesizing and reconciling ideas with other ideas (Basseches & Gruber, 1984; Duron et al., 2006; Fisher, 2011; Glaser, 1985).

Dialectical thinking is a kind of critical thinking that focuses on articulating and resolving conflict (Brookfield, 1987). As an approach to learning, it emphasizes debate and logical deconstruction as constructive learning activities (Carr, 1988; Herreid, 2004). For example, in debate, a student or a team adopts a pro or a con position on a proposition or an argument. Learners elaborate and/or criticize the bases for claims and deductions, present positions and argumentation, and try to understand the positions and arguments developed by other students representing opposing and diverse positions. They resolve conflicts through qualifying and/or synthesizing diverging positions, ultimately creating new ideas (Carroll et al., 2016).

Dialectical constructivism can be contrasted with other constructivist pedagogies in three respects. First, dialectical constructivism specifically emphasizes argumentation and debate among learners. The student's role is to challenge and modify perspectives, not just to learn them, or even just to put them into practice (Carr, 1988; Herreid, 2004). Sanders et al. (1994) showed that college students could be systematically instructed to effectively and non-aggressively deconstruct arguments. Through putting students in a dialectical activity, they would learn how to build up persuasive arguments and how to collect strong evidence to support or rebut others' ideas.

Second, relative to other constructivist pedagogies, dialectical constructivism emphasizes the synthesis of new perspectives. This stance varies from both exogenous constructivism, which emphasizes *adoption* and *enactment* of preexisting (authentic) knowledge and practices, and endogenous constructivism, which emphasizes the *coordination* and *reorganization* of preexisting knowledge and practices (Land, 2000; Moshman, 1982). Further, dialectical constructivism depends on bottom-up anchoring and appropriation, but further engages conflict in understanding (Piaget & Inhelder, 1969) and in cultural-material values (Vygotsky, 1978) to evoke sense making. As Kuhn (1999) put it, "The developmental goal is to put people in metacognitive and metastrategic control of their own knowing" (p. 24).

Finally, relative to other constructivist pedagogies, dialectical constructivism emphasizes that knowledge is problematic and contingent, that people are responsible for constructing it and critically assessing it, and that the challenge of problematic and contingent knowledge is unending (Dalgarno, 2001; Land & Hannafin, 1996). Articulating questions, recognizing information needs, positioning relevant information resources, and synchronizing theories and evidence are all effective practices for developing critical thinking skills (Land, 2000; Land & Hannafin, 1996; Rakes, 1996). In problem-based learning, in contrast, the focus is on learning and enacting authentic concepts and practices, but not necessarily on reflecting upon the limitations and ephemeral validity of the authentic materials.

Mundane Infrastructures in Support of Critical Thinking

It can be difficult for instructors to guide and support students' collaborative learning activities, particularly when the activities are substantial—involving significant reading and analysis that might take place over days or even weeks. In this section, we describe a series of mundane infrastructures that we have investigated to support debate-like critical thinking activities. The infrastructures are "mundane" in the sense that they are relatively straightforward to adopt. Existing platforms for learning management can be reappropriated to support critical thinking activities. For example, Piazza is a widely available platform for developing question–answer discourses as learning activities and resources. We remapped Piazza's "Question" field to the role of arguing a "pro" position in a debate and remapped Piazza's "Student Answer" field to argue the corresponding "con" position. Students were taught Toulmin's (1969) rhetorical categories for structured argumentation and then encouraged to label the propositions in their pro and con positions with Toulmin "tags." As illustrated in Fig. 1, this allowed us to host a collaborative pro–con debate activity in the Piazza Q/A workspace: in the figure, students developed their pro position in the Question field (1) and con position in the Answer field (2), labeling their propositions with Toulmin tags (3). Piazza's content management tools (5,6) provide students with an overview of their argumentation.

The strategy of reappropriating an existing and widely available platform leverages many efficiencies. For example, our students already had free access to Piazza, and several already knew how to use Piazza. Piazza already had created and was maintaining a secure and reliable platform; if there had been any technology issues, Piazza provided a robust technical support infrastructure. More specifically, Piazza had implemented the core "wiki" functionality that our concept of online debate required; that is to say, students could access the debate activity anytime and anywhere and edit their pro and con position. Piazza also tracks editing histories of student content, making it clear who contributed what to debates, encouraging

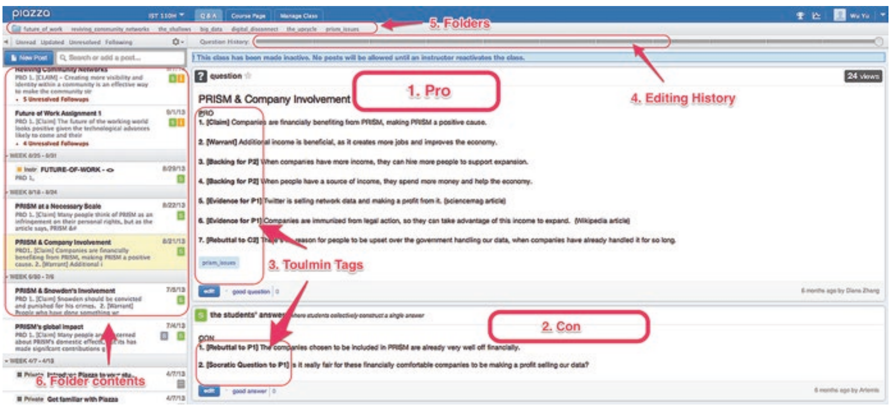

Fig. 1 Pizza platform in support of dialectical activities (Carroll et al., 2016)

students to feel accountability for their participation in the debate activities, and provides an associated discussion forum for each debate so that all members of the class could participate broadly in the activity. In sum, Piazza provided a comprehensive online space for students to post their ideas and keep track of their debate process. Importantly, students were able to reappropriate Piazza for the debate activity. They were able to effectively carry out the debate activity in a platform designed, developed, and labeled for other learning objectives and pedagogical activities (Carroll et al., 2016). Our reappropriation of the Piazza platform also helped us identify further design possibilities. For example, we noticed that students had to work to directly contrast pro and con argumentation—in Fig. 1, pro and con points that correspond are numbered to make it easier to contrast corresponding points. This suggested to us that presenting argumentation in two columns might be significantly more effective in encouraging students to critically contrast corresponding arguments. Thus, we designed the Critical Thinker tool to support the same pro/con critical analysis of argumentation, but to display pros and cons in a horizontal layout, as depicted in Fig. 2.

Indeed, it was easier to understand and contrast pro–con argumentation that was presented in the two-column format, illustrating the importance of visualization to support critical thinking (Sun et al., 2017). Further, we were able to support synchronized collaborative or team-based editing in Critical Thinker, allowing for more than one student to have the ability to edit shared text simultaneously, supported by real-time notifications that provided team members awareness of changes other users were contributing and allowing for a better coordinated activity.

Instead of reappropriating some else's platform, we created Critical Thinker specifically to support pro/con critical analysis of course reading. Critical Thinker itself, though, can also be considered a mundane infrastructure in the sense that it

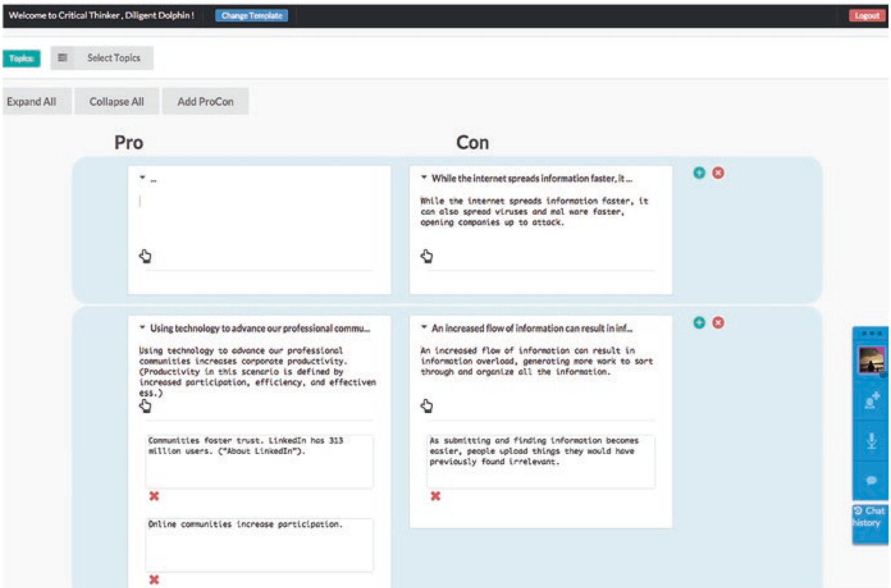

Fig. 2 Critical thinker platform in support of juxtaposed pros and cons (Sun et al., 2017)

was a relatively small software project and provided a fairly specific set of functionalities to create and edit pro/con argumentation. One reason to create a tool like Critical Thinker is that it allows users to have a high level of control; for example, control over the exact placement, timing and wording of the real-time notifications used to enhance awareness of other students' activity. The cost, however, is that the instructor must provide system maintenance. Thus, we had to support user accounts and authentication, server management, and regular updating driven by updates in software we used to create Critical Thinker.

In the previous example, the course supported with Piazza and Critical Thinker was a freshman seminar in information science. Students would read and analyze fairly accessible and controversial topics such as the PRISM surveillance program (Fig. 1), possibilities and risks, and "big data," and effects of the Internet and apps on cognitive development. We were interested in exploring the generality of online debates to other kinds of courses. We used the same kind of pro/con debate activity to support a Ph.D. core course that surveyed concepts and frameworks used in human–computer interaction research, for example, gesture and tangible interaction, design of implicit interactions, and sense making (Fig. 3). Students used a free online debate platform, Kialo (Beck et al., 2019). As is shown in Fig. 3, Kialo

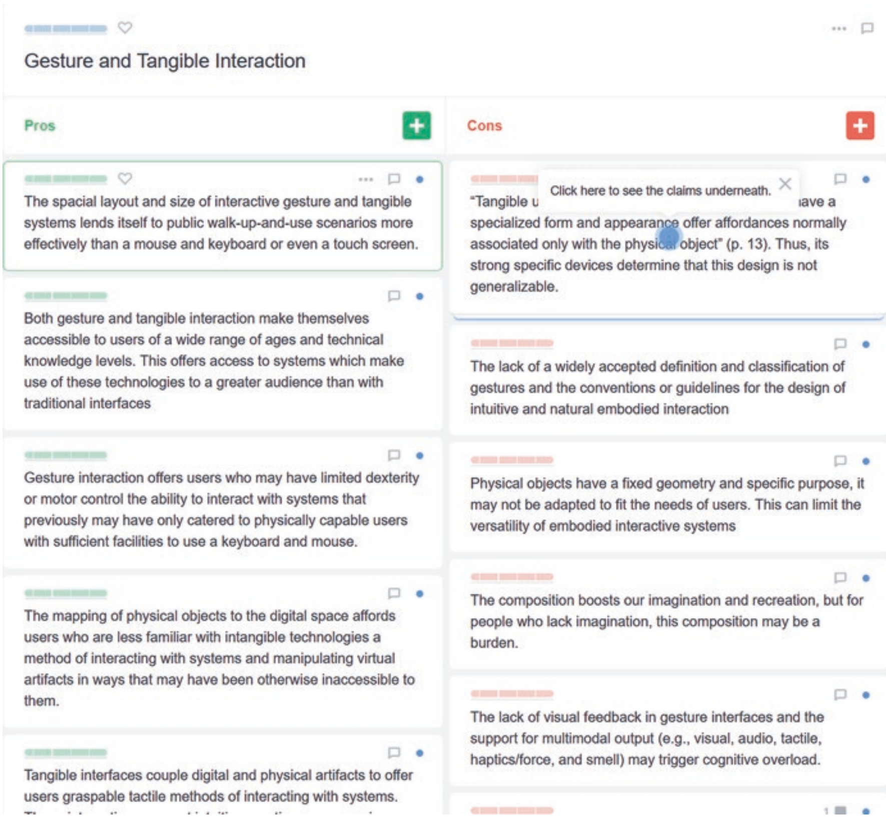

Fig. 3 Kialo platform in support of pros and cons discussion

structures debates with parallel pro and con columns, though the individual points are not aligned (that is to say, the con displayed to the right of a pro point is not necessarily a response to that pro point). In this regard, it is different from both our reappropriation of Piazza and our subsequent Critical Thinker design.

An interesting feature of Kialo is that it allows students to develop a pro/con deconstruction of any proposition in an argument, thus, each of the pro and con points displayed in Fig. 3 could also have its own separate, embedded pro/con analysis. Indeed, if there were an embedded pro/con analysis, say, of the first pro point in Fig. 3, the pros and cons of *that* analysis could also be analyzed by further and deeper pro/con analysis. Also, associated with every pro or con point, there is a discussion forum in which participants in a debate can discuss where they think that particular point should be positioned in the overall argumentative structure.

The Kialo platform hosts a large online debate community (Beck et al., 2019). The range of debate topics and the richness of the various debates throughout the community are impressive. This makes Kialo a great mundane infrastructure for adoption by instructors, allowing for both students and instructors gain the pedagogical benefits of a standard platform that we identified earlier with respect to Piazza, but also the additional potential benefits of becoming associated with the Kialo community, which has adopted critical thinking and debate as an integrative community focus.

The fourth and final example of mundane infrastructure for critical thinking is an activity designed in Canvas, a widely used learning management platform. One of the simplest objects in Canvas is the page, typically used by instructors to present static information. However, Canvas pages can be configured to permit student editing, and when configured to allow editing by multiple authors, possess simple wiki functionality, which possesses a number of pedagogical benefits for collaborative and team learning. Like Piazza, Canvas maintains a history stack, which supports awareness and documentation of all user contributions to the pro/con argumentation. Like Piazza, Canvas does not manage buffers, allowing contributors to accidentally overwrite one another's contributions, while also documenting such actions. As illustrated in Fig. 4, a two-column table template was implemented using Canvas pages and then students were asked to carry out a debate. As in Critical Thinker, horizontally aligned pro–con pairs are logically related; the pro point defends or strengthens the arguments of the reading the students are analyzing (in this case, *The App Generation*), the con questions, criticize or refute arguments from the reading.

Group Formation and Management

We view small-group collaborative learning, such as the debate activities described above, as touchstones for education. Learning in groups naturally creates significant interaction among students in which students take initiative to organize and coordinate work, to explain things to one another, and synthesize collective outcomes. As

Pro/Con Wiki for "The App Generation"

Purple Team List of PRO points with evidence **(defend/strengthen arguments of the book)**	**Blue Team List of CON points with evidence** **(question/criticize/refute arguments of the book)**
Generations have been defined by the moments when we are born in this world to when we mature over the years. The App Generation has not been defined by any significant political and/or economical events but rather, by the technology people utilize. The App Generation is a generation that is pushing forward the concept of finding out what people specifically want, when people want it, how people are processing these information, as well as what comes next and where people will end up. There are two ways in which this generation is being characterized as the "App Generation". One sense would be how people are utilizing these applications. Either digital or nondigital, people are utilizing these applications with hopes that they will instruct them on how to accomplish what they want as quickly and as efficiently as possible. If one of these "apps" does not work to their advantage, they will I simply look for another. And if they cannot find or invent one, they'll quit on our concerns. The final characterization would be how they are examining their lives. While every individual's experience is extremely different, each of their lives will follow some specific pattern of high school, college and then concluding with a job at their dream company.	The authors make a solid argument that we are currently in the "App Generation" and how the current youth are becoming dependent on applications that are found are their smart devices. Although, the current youth are relying on technology to grow and develop, has that been proven yet to be a completely terrible thing? Yes, the book provides countless studies how the current generation is more self-focused and tend to be less sociable compared to previous generations due to technology. Apps and smart devices and social media are still "new" compared to the rest of modern history and we do not know what effects they will have in the future as of now. There is no data to support that using apps to determine how to something is a bad thing. What apps are allowing the current generation is to problem solve. Like mentioned in the pro argument if there is not an app that does a specific task, then someone invents it. The use of apps and technology is making people more intuitive and still giving the same knowledge they would get from learning in a school setting just in a different form. In terms of individual experiences the authors argue that the current is following the same pattern of high school, college, and then finding a job, and although for a majority of people that is the path they are taking is that

Fig. 4 Canvas page pro/con wiki in support of dialectical learning activities

we mentioned earlier, most of our own experience with such learning collaborations involves relatively small class contexts of a couple dozen students or fewer. Many university courses have higher enrollments than this, and the contemporary landscape of education includes extremely large courses such as MOOCs (Massive Open Online Courses) which can have tens of thousands of students. Additionally, we know specifically that such large courses often do not effectively address group formation, management, or peer evaluation (Zheng et al., 2016).

We posed to ourselves the question of how larger classes can benefit from incorporating small-group learning activities, and what modifications or considerations are needed to effectively implement these activities with larger numbers of both students and groups. There are several key challenges. One is group formation, or the assignment of students to specific groups. For several reasons, this challenge is greater than that of dividing a class of n students into k groups. The first reason is enrollment turbulence; which occurs when students add and drop for several weeks early in the term or semester. This turbulence usually does not have a significant negative impact on the overall class context, but at the group level, 1–2 student withdrawals can significantly undermine a small group of 3–4 students, requiring a refactoring of groups, potentially multiple passes of refactoring. For a class with ten times greater enrollment, this challenge is at least ten times greater.

A second potential concern for forming groups is consideration of the diversity among students: For example, in the information science discipline, it is typical that students vary enormously with respect to their motivation and skill in project planning and coordination, graphic design, software design and programming, and writing text. As for enrollment turbulence, the challenge of accommodating student diversity rises with class size; the range of student differences will be greater in a larger class, and it will be more challenging to organize groups that optimally accommodate diversity. Students also have an amazing range of curricular and extracurricular activities that create scheduling complexities for engaging in group activities outside of class. Here diversity becomes a bigger challenge in larger courses as it just amplifies the challenges that can be already present in smaller classes.

Beyond group formation is the consideration of group management. A key challenge in managing groups is interpersonal conflict. Conflicts in small groups can escalate from a mere failure to connect or effectively collaborate, to more serious scenarios in which some members ostracize one another, withhold their participation in the group, or even stop participating. These patterns have consequences for grades, of course, which brings the group conflict to the instructor. The unpleasantness of such situations, and the problems of moving students around in groups mid semester is a reason why faculty members sometimes prefer not to embark on collaborative learning designs. This is more notable in courses where the enrollment size is bigger as it requires more micromanagement of a bigger amount of student groups.

Hence, instructors who incorporate small-group learning into their courses will face the challenge of grading group papers, presentations, and other outcomes. A default approach is often to assume that students contributed roughly equally and to assign all group members the same grade. However, this approach may aggravate existing group conflicts, where there are tensions around group participation, while also potentially disenfranchising individual group members. In other cases, the default of assigning the same grade to all members could help to create or exacerbate group conflicts, because contribution was not equal. More generally, assigning the same grade to all group members implicitly suggests free riding, allowing for a general feeling of unfairness to emerge from the poorly managed collaborative or team-based pedagogical approach.

A more comprehensive and articulated approach to team management is to externally validate the equal contribution assumption through self-and peer-assessments. For example, using the online tool CATME can be an effective approach, allowing each member of a group evaluate the contribution of themselves, as well as of their fellow group members. Self-evaluations of group contribution can be useful and illuminating, but can also be defeated by students who assign the same scores or contribution ratings to all group members. Interestingly, using a tool such as CATME can often still result in student frustration and complaining that group members are contributing too little.

The challenges of enrollment turbulence/group refactoring, of accommodating diversity in group formation, and of tensions around self-evaluation of group contribution motivated us to investigate scale-free small-group learning (Zhu et al., 2018). This approach employs frequent pseudo-random reassignment for group formation and management, for example, randomly assigning students to groups and then to reassigning them to other groups (that is, with different students, insofar as that is possible) for each separate assignment in the course. This approach leverages the idea of refreshing the groups frequently as a way of mitigating the chaotic impacts of enrollment turbulence/group refactoring and tensions around self-evaluation of group contribution, increasing each student's chance of having positive, albeit briefer, collaborations with other students. It addresses the challenge of diverse student preferences and skills by exposing each student to the greatest possible (random) variety of classmates. Importantly, this approach to group assignment and reassignment also minimizes instructor management; if there is a conflict within a group for a given assignment, the problem will be addressed for the next assignment anyway. The concept of pseudo-random permutation can be extended to peer grading. Peer grading evokes metacognitive reflection on an assignment a student has recently completed themself, especially when the grading requires comments and suggestions, not just judgements. For each assignment, a set of peer graders is assigned to each group—again, with the pseudo-randomization constraint that the graders did not grade any of the group members before, or immediately before, and that none of the group members graded them, etc. The peer graders make comments and assessments, which are anonymized and collated for the group that was graded. In turn, the group members assess the grading feedback they received. Grading disputes can be escalated to a second round of grading. Ultimately, disputes would be reviewed by the instructor, but it is likely that even after two rounds of grading, a consensus would emerge. On the other hand, students receive a lot of feedback on their work, and they also reflect metacognitively on the assignment and provide feedback to others. This design involves relatively modest direct group assessment from the instructor.

This work is predicated on the assumption that if collaborative learning were easier to manage and were more scalable, then more faculty would adopt collaborative approaches. We have started to test this assumption (Zhu et al., 2018), but we are still at the stage of demonstrating that our approach meets its technical goals. Computer and networking infrastructures to enable broad use of scale-free small-group dialectical learning activities is fairly standard in American universities currently. Thus, while there is still a "digital divide" in the world, technology access is not a critical obstacle on American campuses (in the sense of Ertmer, 1999). A more formidable obstacle is the pedagogical belief and practice of faculty, views about what is possible, reasonable, or easy to do in teaching (Ertmer, 2005; Kim et al., 2013).

Discussion

Identifying authentic and engaging learning activities is a continuing challenge in education. Today, pervasive digital mediation makes it obvious that an important learning resource for authentic and engaging learning activities is other learners. Thus, the challenges of active learning pedagogies are now social as well as cognitive. Here we suggest an approach based on critical and dialectical thinking where students can take an active role in their own learning by creating and modifying their own perspectives. We argue that, pedagogically, this approach can help students create authentic knowledge and learning not based solely on mere remembering.

A key difficulty of initiating and sustaining various collaborative learning regimes is an issue insofar as students as well as faculty often see class management time as an overhead or tax on learning time. However, effective interventions ought to be appropriable pretty much instantaneously and/or through activity that students and faculty can understand as directly related to the core mission of the course. Still, this remains a prevalent issue in that there is still a need for mundane tools that can be effectively used for instructors with this purpose in mind. We have talked about reappropriation of tools, such as Piazza, and the use of Kialo, the latter being a better suited tool and a more widespread one. Nonetheless, we argued that even if we were to use other tools for debating, those should be easy to adopt and straightforward to use. Moreover, in thinking about using these types of tools, they need to facilitate class management and not create another set of issues.

Students are uncertain about whether outcomes they come to on their own are valid. They seem to want and need critical input. They want the instructor to work through their ideas critically, but they also want constructive suggestions about where to go further with their own initiatives. This learning dynamic should be researched further. To minimize this constraint, we have suggested the use of pseudo-random permutation on peer grading. Knowing that peer grading creates metacognition reflection of one's learning can help students settle their doubts or concerns about their own learning and whether the interactions have been meaningful and valid. In this scenario, students are able to provide feedback to each other, while at the same time able to receive feedback from the instructor to further validate their ideas.

Our works imply that students could engage with the course contents and the instructors in different modes. However, the technology may not be well-prepared today, which requires future studies and developments. The technology-enabled collaborative learning had been shown useful for improving student cognitive performance, promoting social interactional, and positive learning behavior. Several solutions (e.g., the two services we mentioned in this chapter) have been employed in classroom and online teaching—the interaction between different teaching modes worth studying further to respond to future educational needs and goals.

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Team Learning in a Technology-Driven Era

Jody K. Takemoto, Drew Lewis, Christopher W. Parrish, Leanne Coyne, and Christopher M. Burns

Abstract Today's students are team-oriented, confident, and dependent on technology. These attributes are coupled with a desire for immediate feedback to promote improvement. However, they are dampened by a lack of socialization, collaboration, critical thinking, problem-solving, and communication skills (Shatto and Erwin, Creative Nurs 23:24–28, 2017). Educators must adapt to address these needs and promote attainment of these skills for both collaboration and competitiveness in the workplace. To accomplish this goal, an evolution from traditional learning to team learning using technology is imperative. An overview of active learning strategies is discussed with a focus on team-based learning (TBL), including the additional benefits of TBL and the use of complimentary technology.

An Introduction to Active Learning Strategies

Generational differences require changes in teaching and learning strategies (Shatto and Erwin, 2017). TBL is a collaborative pedagogy designed to promote collaboration, communication, critical thinking, and development of problem-solving skills. Before focusing on TBL, we will review other common active learning strategies.

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Two pedagogies that are readily implementable in most courses are Peer Instruction and Peer Led Team Learning. Peer Instruction is characterized by lectures punctuated with think-pair-share activities. Here, students are posed a problem, first think about it individually, then pair with a neighbor to discuss. Responses are then shared, often via audience response systems (ARS) (Mazur, 1997). Peer Led Team Learning involves supplementing a course's lectures with weekly workshops led by a peer leader. These workshops involve students working in groups of eight to ten on challenging inquiry tasks (Gosser et al., 2000). However, both approaches can be broadly construed as complementing lecture rather than replacing it, and the full benefits of active learning may not be captured.

Many pedagogies fall under the umbrella of Flipped Learning, which is defined by students first encountering new material individually (usually outside of class) through structured activities, then using the classroom environment for activities (Talbert, 2017). The broad category of Flipped Learning prescribes very little about what happens during class meetings, which has given rise to several different implementations. SCALE-UP is one such implementation arising from physics education; students complete readings and quizzes before class and collaborate on challenging activities during class (Beichner, 2007). While the structure of these activities is not well specified, SCALE-UP classes assign team members to rotate through specific roles each class period. Just-in-time teaching is another flipped learning pedagogy that is even less well defined, characterized by students completing individual assignments before class and the instructor tailoring the day's lesson based on student responses (Novak, 2011).

TBL is most often implemented as a form of flipped learning. Like SCALE-UP, TBL includes prework before class, an individual and team quiz on the prework, and tailored just-in-time teaching by the instructor based on the results of the quizzes. Unlike SCALE-UP, TBL includes peer-teaching during quizzes and structured problem-solving activities, which provides guidance to instructors in developing engaging and meaningful class activities.

Problem-based learning (PBL) is another active learning pedagogy characterized by students collaboratively identifying and solving authentic problems. Problems require students to acquire content knowledge to solve them independent of the instructor (Barrows, 1996). One type of PBL is case-based learning, in which the authentic problems are case studies. While PBL is prescriptive about the kinds of class activities that take place, it does not dictate preparatory activities. PBL is not mutually exclusive from TBL, which also involves nonprescriptive preparatory activities and often involves activities based on case studies.

A third category of active learning pedagogies is inquiry-based learning. Inquiry learning pedagogies require students to be tasked with developing/discovering knowledge through completion of scaffolded activities. One such pedagogy is Process Oriented Guided Inquiry Learning (POGIL) (Farrell et al., 1999). POGIL, like SCALE-UP, involves students solving challenging inquiry activities after being assigned a specific role.

While, TBL is most often implemented as flipped learning, Lewis et al. (2019) recently introduced team-based inquiry learning (Lewis et al., 2019). In alignment with constructivist principles, learners in inquiry-based learning (IBL) scaffold and discover new knowledge. In team-based inquiry learning, a combination of IBL and TBL, quizzes are focused on reviewing prerequisite knowledge so that extraneous cognitive load is reduced in the ensuing activities. The collaborative aspect of TBL provides students with support as they complete challenging inquiry activities during class.

Team-Based Learning in Theory and Practice

History

TBL was first developed in the late 1970s by Dr. Larry Michaelsen when his classroom changed from 40 to 120 undergraduates. After consideration of this “daunting pedagogical challenge,” Michaelsen reflected upon the group work that he was previously using to teach students (Michaelsen et al., 2004). In these group activities, students applied fundamental concepts to solve problems. After finding that this teaching strategy was well received by students who appreciated having different perspectives shared by their peers in their groups, students taking ownership of their learning and their peer’s learning, and that this strategy helped transitioning groups to teams. Michaelsen refined his teaching strategy based on feedback he received and demonstrated at faculty development workshops, resulting in the formalization of TBL as a teaching pedagogy and andragogy (Pew, 2007). Although Michaelsen’s original approach to TBL requires minimal technology, over the years TBL practitioners have found integration of various technologies to be advantageous.

Team-Based Learning Fundamentals

While TBL can be effective for teaching learners of all ages, limited studies demonstrate its use in grades K-12 (Jarjoura et al., 2015; Wanzek et al., 2014). However, TBL is frequently used in health education and to a lesser extent in postsecondary education in STEM disciplines (Haidet et al., 2014; Liu & Beaujean, 2017).

TBL is a structured teaching strategy that follows specific sequential steps that can be adopted into any classroom. TBL is flexible to include technology to enhance instruction, adapt to various time constraints, meet the needs of different learner levels, and discipline nonspecific (Michaelsen et al., 2004). TBL has three phases: (1) preparation, (2) readiness assurance process (RAP), and (3) application exercises (tAPPs) (Fig. 1).

In the first phase of TBL, instructors select materials that prepare students for in-class activities prior to class. Students use learning objectives to guide

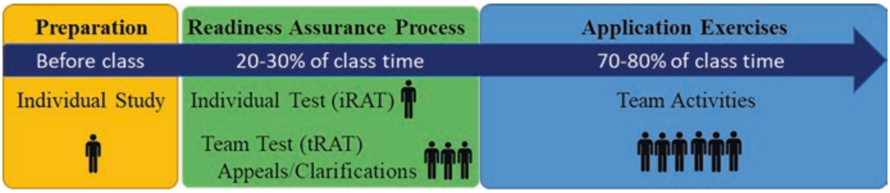

Fig. 1 Phases of the TBL Process. *iRAT* individual readiness assessment test, *tRAT* team readiness assessment test

preparation activities. The prework may include textbook excerpts, handouts, videos, and/or self-assessments.

Students report to class and the RAP begins with a short quiz (readiness assurance test; RAT) comprised of multiple-choice questions about the prework first completed individually then as a team. During the tRAT, team members negotiate the best answer choices after coming to consensus. This is an opportunity for peer-teaching. Students receive immediate feedback on correct and incorrect answers during the tRAT to ensure that students understand the fundamental concepts necessary to apply to solving problems. The only resources teams can use are each other's memory. At the end of the RAP, instructors provide clarity on misunderstood concepts that teams were not able to resolve, to ensure that all students have the same prerequisite knowledge before starting tAPPs. The RATs are typically graded, but very low stakes to promote careful preparation without changing the emphasis from TBL being a learning activity versus a testing activity. Some instructors include an opportunity for teams to appeal a question if they believe their answer is superior to the one provided with a valid reference. The RAP is intended to motivate students to come to class prepared and provide faculty feedback on student readiness to participate in tAPPs.

The last phase occupies most of class time. During this phase, teams apply fundamental concepts to solve challenging problems (tAPPs). tAPPs are structured around four core principles, known as the 4S's. The 4S's are: (1) teams work on the *same problem*, (2) the tAPP question is a *significant problem,* representative of a real-world issue with answers not easily searchable on the internet, (3) teams negotiate and consense on a *specific choice,* and (4) after teams made a specific choice, teams *simultaneously reveal* their answer.

Why TBL Works

Current publications on TBL evaluate teacher and learner perceptions and learning outcomes (Reimschisel et al., 2017). The growing body of studies on the achievement of learning outcomes using TBL is attributed to adherence to TBL best practices, including incorporation of the essential elements, backward design, and theoretical underpinnings.

Essential Elements

Central to TBL's success are high-functioning teams and well-designed team activities. To accomplish this, there are four required "essential elements" (Michaelsen et al., 2004):

1. Well-designed team formation: "Permanent" teams, typically with five to seven members that distribute resources (e.g., experience, perspectives). Groups require time to transform into teams. Keeping the same team for one semester is recommended. Distribution of resources encourages diversity in approach to critical thinking and problem-solving.
2. Accountability: Inclusion of a method motivating learners to be accountable to themselves and team members. It is imperative that individuals come to class prepared with knowledge of the fundamental concepts to perform well on the iRAT and engage with team members on the tRAT and tAPPs.
3. Group activities: Challenging activities where teams apply fundamental concepts to solve problems while team members practice communication, critical thinking, and problem-solving skills to select the best answer collaboratively; bolstering learning and team development.
4. Immediate feedback: Consistent and timely feedback informing learners of their progress towards mastery of topics by promoting self-regulation, self-efficiency, and self-motivation. Feedback helps to foster the transition of the group to a team.

Backward Design

Backward design is a critical component of TBL module development. Backward design involves designing with the end in mind, specifically, starting by writing effective behavioral learning outcomes of what students are expected to achieve at the end of the course/module (Wiggins & McTighe, 2005). Backwards design is contrary to the traditional approach of starting by assigning textbook chapters and incorporating antiquated learning activities without association to achievement of desired results. When backward design is applied to TBL module development, instructors start by developing learning outcomes for the course and subsequently for the module. Appropriate assessment measures are then selected, and tAPPs designed to facilitate students' application of the foundational concepts to real-world problems are developed. Lastly, prework is selected, and RAT questions developed. This design process is imperative to the success of TBL.

Educational Theories Supporting TBL

Several educational theories support the success of TBL including constructivism, social constructivism, self-determination theory, cognitive learning theory, and social cognitive theory (Kay & Kibble, 2016). A hallmark of these theories is the idea of active student engagement in the learning processes. Social learning is the notion that learning happens through interactions with other learners.

Central to constructivist ideas is the belief that learning is constructed from previous learning, and through interactions with the environment (Ornstein & Hunkins, 2017). Hrynchak and Batty (2012) describe TBL in the context of constructivism due to the shifts in learner and instructor roles and active learning exercises where learners solve authentic problems (Hrynchak & Batty, 2012). Team member discussions, immediate feedback from tRATs, tAPPs, other learners, and instructors, and reflection opportunities through the RAP and peer evaluation support social aspects in learning.

In social cognitive theory, an agentic view is required (Bandura, 2005). It is argued that learners are not required to actively participate in the activities but can choose to learn through observation. Learning is fostered through an agentic behavior of self-organization, self-regulation, and self-reflection. TBL is supported by social cognitive learning theory as learners are engaged in their circumstance. This is initially exemplified in the preparation phase as learners devise a learning strategy and monitor progress towards learning fundamental concepts to be successful on the iRAT, in tAPP discussions, and receipt of peer feedback. The use of TBL increased student's confidence in learning self-care concepts, lending itself to social cognitive theory (Frame et al., 2016).

Self-determination theory is best understood as "an approach to human motivation and personality…that highlights the importance of humans' evolved inner resources for personality development and behavioral self-regulation" (Ryan & Deci, 2000). This theory has three innate psychological needs that must be met, autonomy, competence, and relatedness. Motivation is described as a mediator in this theory that influences learners towards growth and well-being. TBL meets the psychological need of autonomy with students having complete control over how they prepare and engage with all facets of the learning material, other learners, and the instructor. Competence is achieved in TBL through feedback and discussions on tRATs and tAPPs, which inherently increase intrinsic motivation, and is suggested to increase engagement. TBL also addresses the psychological need of relatedness, in that the team provides an environment where learners feel a sense of belonging (Jeno et al., 2017).

Adherence to the traditional TBL framework is important to achieve desirable learning outcomes measured by exams and standardized tests; whereas, "dysfunctional TBL" was suggested to have a negative impact on student learning experiences and outcomes (Burgess et al., 2014; Dharmasaroja, 2020). Collectively through the support of these various theories, TBL is a successful teaching pedagogy and andragogy.

Transferable Skills and Collateral Benefits of TBL

Studies show that employers seek graduates who can work in teams, communicate, and critically think effectively; skills that many employers feel graduates are missing upon entering the workplace (Appleby, 2000). The various life-skills fostered by TBL are discussed.

Critical Thinking and Problem-Solving

Critical thinking is a mental process of active and skillful synthesis and evaluation of information that leads to a decision (Papathanasiou et al., 2014). Strong critical thinking skills afford an individual the ability to identify key issues, uncover assumptions, identify relationships, make inferences, deduce conclusions, and evaluate the validity of conclusions (Terenzini et al., 1995). Critical thinking is not typically learned unless it is taught, yet finding time in busy student schedules to provide specific training in critical thinking may be difficult (Roksa & Arum, 2011). Educational strategies that inherently develop critical thinking skills while students acquire/apply knowledge are essential if students are to become effective critical thinkers. Through systematic problem-solving, TBL provides an opportunity to improve critical thinking skills while delivering discipline-based content (Bleske et al., 2016). Students practice critical thinking throughout the TBL process; namely during preparation, intra-team discussions, reevaluation of options after selecting an incorrect tRAT answer, and when debating the best answer when presented with several viable options in the tAPPs.

Independent learning, such as pre-class preparation, is influenced by the extent of a learner's critical thinking skills (Kopzhassarova et al., 2019). Independent learning requires students to identify their own strengths and deficiencies, which concepts are most important to understand, and what information they should focus their time on to most effectively support learning these concepts (Kopzhassarova et al., 2019). Arguably, by practicing independent learning, students are also practicing their critical thinking skills. Pre-class preparation for TBL is superior to many types of independent study as (1) the first step students undertake in a new TBL module rather than the last step, providing a scaffolding for learning; (2) guided by learning objectives, helping students to identify key areas to focus their study; and (3) students are motivated to study in preparation for the RAT. TBL, therefore, encourages students to practice independent study more consistently and efficiently than most other teaching strategies.

Intra-team discussion during tRATs and tAPPs requires students to defend their choices and to evaluate any conflicting choices made by their peers (Sibley, 2014). Students must then evaluate options discussed to select one answer. Defending their choices requires that students collect and present evidence to support their answer. Conflicting opinions requires that students evaluate the evidence presented by their peers with the evidence they themselves presented. Finally, students must decide which choice has the most evidence in its favor. Completing the same quiz as a team enables students to discuss the best possible answer and arrive at a decision collaboratively (Sibley, 2014). It is in the best interest of each student to undertake this process collaboratively rather than competitively, as if teams do not solve the problem, no one on the team will receive credit. This provides motivation for students to listen to the opinions of every team member rather than relying on only their perspective.

Immediate feedback during the tRAT provides a distinct opportunity to critically think through a problem (Persky & Pollack, 2008). When teams select an incorrect answer, they are provided with immediate feedback that their choice was incorrect. Teams then reevaluate the remaining options and select a different choice. Students can revisit and evaluate flaws in their original logic that resulted in making an incorrect choice (Sibley, 2014). Thus reflecting on any errors, omissions, or assumptions that may have originally been missed, a key element of improving critical thinking skills (Lundquist, 1999). Reevaluating the remaining options, while conscious of their original error, encourages students to evaluate choices more critically; requiring the use of and refinement of higher order thinking skills (Allen et al., 2013).

tAPPs are designed to encourage students to select the "best" answer rather than the "correct answer" (Janke et al., 2019). This is reflective of real-life problem-solving and requires students to compare the advantages and disadvantages of each option and select a choice (Parmelee & Michaelsen, 2010). Like the tRAT discussion, by working through tAPPs in teams, students must consider different perspectives and integrate them into the final decision. During the whole class discussion, where teams defend their choices to one another, individual students must be prepared to support their team's choice (Brokaw & Condon, 2013). Preparation for this discussion encourages students to actively engage in the intra-team discussion, ensuring readiness to defend their team's answer (Brokaw & Condon, 2013). At the conclusion of the whole class discussion, the content expert provides their opinion of the best answer choice, requiring students to consider the expert opinion compared to their own. This viewpoint of the critical thinking process undertaken by their instructor trains students to ask the right questions when faced with challenging problems.

Evidence of the effectiveness of TBL in developing critical thinking skills, McInerney and Fink (2003) found that student perceptions of their own critical thinking skills improved with TBL (McInerney & Fink, 2003). Further, researchers found that student performance on a standardized critical thinking assessment significantly improved after 2 years of TBL instruction (Silberman et al., 2021). TBL, while simultaneously teaching students discipline-based content, also develops critical thinking skills, emphasizing the benefit of this pedagogy.

Communication

Communication is frequently mentioned as a skill that students can improve through TBL (Ofstad & Brunner, 2013). Unsurprisingly, as the in-class components of TBL are primarily comprised of discussions. During intra-team discussions, students communicate their own ideas, argue their points, and listen to the ideas of their peers. Each student may have a different perspective on the problem that can contribute to selecting the best answer choice. It is often necessary for students to coach their peers on their understanding of the concept. This peer coaching improves interpersonal communication skills (Christensen et al., 2018). It also helps students to understand that disagreements and debates over answer choices are beneficial to learning and helping students to learn how to disagree professionally (Christensen et al., 2018).

Debating answer choices is a fundamental component of the learning process in TBL (Hrynchak & Batty, 2012). Debate has been shown to improve students' ability to communicate their own ideas, to improve their composure during discussion, and to boost their confidence (Hrynchak & Batty, 2012). Students also report a perceived improvement in their verbal and nonverbal communication skills after debate exercises (Hall, 2011). Although TBL does not contain all the elements of a true debate, the frequent need to provide evidence to support their answer choice and defend their decision allows them to practice these skills frequently.

To effectively come to consensus during intra-team discussions and adequately argue against the conflicting opinions during the whole class discussion, students must actively listen to the opinions of others. Studies have demonstrated that students learned to appreciate the importance of active listening in order to reach consensus on the best answer choice (Burgess et al., 2020).

Finally, during the whole class discussion, students are required to communicate key components of the team discussion to defend their answer selection. Frequently speaking in front of an audience can help improve their confidence and skills in public speaking (Bouw et al., 2015). Leisey et al. (2014) found that TBL improved students' ability to communicate in several ways, including facilitating group discussion towards consensus, conveying their own thoughts, and acknowledging the ideas of others. They also proposed that given the requirement of TBL that students publicly present their ideas, unsurprising that students' perceived skills in public speaking improved (Leisey, 2014).

During online instruction, TBL has been particularly beneficial to help students practice their communication skills. While many students endured passive learning through online lectures during COVID-19 stay-at-home orders, thanks to modern-day technology, students in TBL classrooms were able to continue their classes similarly to face-to-face classes. TBL students continued to work in teams, have team discussions, and debate their arguments with their class.

Regardless of the setting, whether in-person or online, consistent and repeated use of various communication skills throughout the TBL process provides consistent practice that is rarely provided by other educational strategies.

Teamwork and Peer/Team Evaluation

Maximization of the benefits of TBL requires high-functioning teams. Many students enjoy the benefits of working within a team and improving their teamwork and individual skills. Other students have prior negative experiences with team projects, often because there was no recourse when individuals failed to contribute to the group, leading to resentment within the team and frustration with the learning method. Peer feedback and evaluation provide students with mechanisms to hold each other accountable promoting team learning and success to overcome these challenges (Lane, 2012).

Many new TBL instructors are bogged down with the logistical challenges related to students providing/receiving feedback or evaluation of other students' and self-performance. These include whether/how to incorporate this into grades, what questions to ask, what tools to use to collect and distribute the feedback, how to reduce students "gaming" the system, and when/how often to use feedback during a course. No simple answer exists to these questions that applies to all or even most situations. It is most important for instructors to consider their students, learning environment, and goals to guide them determining the details on how they will implement peer evaluation in their setting.

Something common among many teachers is the need to overcome negative student perceptions about peer evaluation (Levine et al., 2007; Parmelee et al., 2009) and lack of experience giving or receiving effective peer feedback. One successful approach is to provide students with explicit training in the art of feedback (Michaelsen & Schultheiss, 1989). Although this takes considerable class time and instructor effort, it helps develop a critical life skill students use throughout their future careers.

In addition to peer-peer evaluations, evidence support the value of team-level feedback. This feedback is focused on team behaviors, not individual performance. It makes clear the expectation that teams should be developing teamwork skills and that improving teamwork skills can lead to improved performance and learning outcomes. Students may find this less intimidating, especially as an introduction to peer-peer feedback that may follow. Indeed, using both team and peer feedback is supported by a recent study that reported student perceptions of these two activities. Students reported that team feedback was more helpful in developing team cohesion and understanding characteristics of well-functioning teams, while peer evaluations were more helpful in improving their own individual contributions (Madson & Burns, 2019).

Peer evaluation promotes socialization into professional teams and improves team performance. These features are becoming more important as students and workers move among different groups in growing online professional communities with little/no time to develop face-to-face relationships.

Self-Reflection/Self-Directed Learning

In addition to reflecting and evaluating their team's and peers' performance, TBL also provides students with ample opportunities for self-reflection and self-directed learning. One common way is by having students complete a self-evaluation as part of the peer-evaluation process so they can compare their own self-evaluation with those of their teammates. The RAP gives students feedback on their individual performance by providing a comparison to that of their teammates'. A key advantage of using immediate feedback in the tRAT is giving students this tool for self-evaluation, which has been shown to promote improved self-identification of learning gaps and increased participation in intra-team discussions.

Some TBL adopters have gone one step further and introduced an add-on activity to TBL that explicitly addresses self-directed learning and lifelong learning skills (Schneid et al., 2019). These skills are both essential for graduates to be successful and increasingly recognized by accreditation bodies. Briefly, students identify a learning gap and formulate a research question, perform literature research to answer the question, and share findings with their teammates including an evaluation of the approaches and resources they used. Students reported that this activity helped them identify and close gaps in their knowledge.

TBL helps students develop self-directed and lifelong learning skills that are required for enduring success in an ever-changing world. The recent upheaval caused by COVID-19 is a poignant example of how quickly people must be able to retool and reimagine their jobs to survive unexpected disruptions to the status quo.

TBL and Technology

To transfer the affordances of TBL to online settings, instructors have begun to implement TBL across various online settings, including fully asynchronous and fully synchronous settings and one specific model—the Integrated Online-TBL (IO-TBL) model—which incorporates both asynchronous and synchronous engagement. Likewise, technology supporting each of the TBL components, for both asynchronous and synchronous instruction, has been identified. The various models of implementing TBL within online settings, as well as the corresponding technology, are discussed.

Practice of TBL

Asynchronous

TBL activities in fully asynchronous courses require no real-time interaction and are completed remote (Sener, 2015). Absent real-time interactions, and activites, elements of TBL are often expanded over multiple days. To start, the RAP is likely to span multiple days. Clark et al. (2018) recommended providing 1–2 days for students to complete their iRATs, following 2–3 days for teams to coordinate and submit tRAT responses. Although students and teams may be provided an extended time period to complete the RAP, iRATs can still be timed, technology can be leveraged to provide immediate feedback on the tRAT, and partial credit may still be awarded on both assessments (Clark et al., 2018). tAPPs are likewise extended across various days and deadlines, which provides opportunities for both intra- and inter-team discussions. Once the tAPPs are released to students, time is designated for teams to collaborate and submit their specific choice. Following, choices are simultaneously reported, and teams may be required to submit justification for their reasoning and engage in inter-team discussions.

Using similar design features, Palsolé and Awalt (2008) implemented TBL within an asynchronous course. It was found that students performed well in the course; likewise, team performance in the course corresponded with the team's frequency of intra-team discussion posts, as well as their level of engagement in viewing other teams' created tAPP products, just as in the face-to-face TBL course. Students also reported a higher level of team satisfaction when asked to compare their experiences with other courses that included formal or informal team learning.

Synchronous

In large classrooms having a classrooms, technology that can be helpful with any size class although, with large classes having a classroom specifically designed for TBL equipped with technology is beneficial. In large TBL classrooms, use projectors or large televisions to display information and activities from the instructor. Additionally, a well-placed podium can facilitate connections from multiple input devices and/or wirelessly so that students can also show their thought processes in arriving at their decisions. Having the opportunity for each team to be able to show what is on their screen with their teams without having to move around the tables can be beneficial. Finally, in large TBL classrooms, microphones that can effectively facilitate the ideas from students across the classroom can significantly impact engagement.

TBL activities in fully synchronous online courses extend all activities to remote settings with real-time interactions (Sener, 2015). TBL in synchronous courses matches the sequence and components of TBL in face-to-face courses. For example, students complete the iRAT individually, then the tRAT in a breakout room with their team, a common feature in web-conferencing tools (e.g., Zoom, WebEx, Teams). Likewise, teams complete tAPPs in breakout rooms, followed by inter-team discussions in the main video conference room facilitated by the instructor. It is important to keep up the level of engagement and presence by keeping cameras on.

Franklin et al. (2016) implemented the same pharmacokinetics TBL module in both face-to-face and synchronous online settings (Franklin et al., 2016). The module was completed in a 2 hour period and included an iRAT, tRAT, and a single tAPP. Students in synchronous online TBL scored significantly higher than students in the face-to-face setting on the tRAT, although there was no significant difference between groups on their perception of understanding. When considering students' perceptions of teamwork competencies and interdependence, while students participating in both the face-to-face and synchronous module indicated positive interactions, students in the online cohorts scored significantly lower on both teamwork competencies and interdependence than the students in the face-to-face cohorts. While time and resource intensive, Franklin et al. (2016) conclude that TBL within a synchronous setting is a "valuable alternative" (p. 6).

Integrated Online-TBL

The IO-TBL model includes elements of both asynchronous and synchronous engagement within each module of instruction (Parrish et al., 2021a, b). Each module begins with a synchronous session that includes the iRAT, tRAT, and one or more tAPPs. As with synchronous TBL, the iRAT, tRAT, and tAPPs are implemented using a traditional TBL methodology. Following the synchronous session, teams complete one to two tAPPs simultaneously, through asynchronous and synchronous modes of engagement. Both tAPPs have the same deadlines, first providing an opportunity for individual and team contributions, followed by an opportunity for teams to view other team's products and/or to submit a specific choice, and lastly, an opportunity for inter-team discussion where students view how all teams responded and provide justification for their team's selection. Within IO-TBL, teams are provided both asynchronous and synchronous options for completing the out-of-class tAPPs. Learners use the designated team discussion boards to collaborate and complete tAPPs (asynchronous engagement) or meet using video conferencing software (synchronous engagement). Regardless of how teams choose to collaborate in identifying a specific choice, the concluding inter-team discussion is completed asynchronously as students are required to individually provide justification for their team's choice considering how all teams responded.

Parrish et al. (2021b) examined students' perceptions of the IO-TBL model within an initial implementation, which included 21 students across two sections. When students were asked what was going well in the course at both mid and end-of-semester, the opportunity to work in teams and synchronous meetings were identified most commonly, both of which are elements of the IO-TBL model. In contrast, when students were asked for specific suggestions on how to improve the course, they focused on specific content and pacing of the course, not elements of the IO-TBL model.

Supporting Technology

In addition to selecting the specific model of online TBL, important considerations are needed in selecting the appropriate technology for implementation. Exploratory technology that is being considered to bolster various facets of TBL includes social media (River et al., 2016) and virtual reality (Coyne et al., 2018). Technology described herein goes beyond "standard technology" such as slides and videos. Beyond the technology used to support the specific components of TBL (e.g., RAP), consideration for the platform(s) used to host the course is needed. While the learning management system (LMS) serves as the central platform for all three models of online TBL asynchronous, synchronous, and IO-TBL, the specific LMS is institution specific. Key features of the LMS include a means to share documents and course content, post discussions or forums, and for students to submit assignments. If available, a helpful feature within an LMS is the option to organize students into teams, which provides opportunities for private, team collaboration, and assignment submission (Parrish et al., 2021a). If implementing synchronous TBL or IO-TBL, a second platform consideration is web-conferencing software. An essential consideration in selecting the web-conferencing software is the availability of breakout rooms, key in providing teams private opportunities to collaborate on the tRAT and tAPPs within a larger class session. Beyond the platforms in which teams will engage throughout the course, technology specific to various components of TBL is discussed.

Prior to the start of each module, preparation materials are shared within an LMS. Gomez et al. (2010) detailed ways in which to incorporate team collaboration during the preparation phase of a module by requiring students to post student notes and discussing various aspects of the assigned readings (Gomez et al., 2010).

Technology used within the RAP includes ways in which to host the iRAT, tRAT, and appeal process. In considering the technology used to host the iRAT, the platform should support a multiple-choice assessment. Additional options of point-spreading or confidence-based testing, a method used to assign their points across many or one answer choice, offer instructors alternatives to enhance TBL. When selecting technology to host the tRAT, assessments must be designed such that teams are provided with immediate feedback to make an additional selection until the correct answer is revealed. Tests and quizzes within an LMS, "clickers" (ARS), Kahoot, Qualtrics, InteDashboard, or OpenTBL, may be used to host either or both the iRAT and the tRAT. While Qualtrics is used to develop and disseminate surveys, it is non-TBL specific. Likewise, an ARS has the flexibility to be used during other TBL phases to intermittently check learner comprehension. InteDashboard and

OpenTBL are both all-in-one TBL systems that not only facilitate iRATs and tRATs but also preparation materials, tAPPs, and peer evaluations. Regardless of which platform is selected, care should be given to ensure the iRAT does not release scores or correct answers until after the tRAT has been completed.

Helpful technology features for completing tAPPs are similar across both asynchronous and synchronous settings. One major factor of importance is the technology required for tAPPs be able to capture real time. Namely, it is preferred that each student can view and access the tAPP, versus only being able to do so from a single device, such as the team leader's (Parrish et al., 2021a). If teams need to create a product or deliverable, while still allowing all students access to the activity, Google Suite, Dropbox, OneDrive, and Jamboard are all viable options. Teams can easily view other teams' products using Google Slides or Jamboard might be considered, wherein each team is assigned a slide to develop a product or provide a response. Once all teams are done, students easily view the other slides and may even leave feedback or comments if instructed to do so. When it comes to platforms that allow for teams to make a specific choice or provide a written response, and allows all students to access the activity, InteDashboard and OpenTBL are both options. The utility of social media to support various phases of TBL remains to be elucidated (Alhomod & Shafi, 2012; River et al., 2016). Social media technologies as well as other real-time software such as Padlet, Lino, and various whiteboard applications are suitable for facilitation of gallery walk reporting. Because of the real-time capabilities, teams can display their responses. Subsequently, teams review all of the options and vote as to which team best answers the question. Voting can be achieved through a variety of software options including PollEverywhere and Zoom. For discussion students seemed to engage more with Facebook for discussions and other course-related posts compared to the LMS (Divall & Kirwin, 2012). Another social media platform used to foster discussion and communication is Twitter. In a study by Wright et al., Twitter was used to enhance communication for a self-study course between students and faculty (Wright et al., 2014). Anecdotally, Facebook, Twitter, and/or Instagram have been incorporated when student groups were to recommend an over-the-counter medication for a patient after reading and reviewing a case.

Technology tools used to complete peer evaluation should provide students an opportunity to provide quantitative scoring, written responses to justify their quantitative scoring, or feedback specific to areas of strengths and improvements. Peer evaluation may be facilitated using all-in-one TBL systems, such as InteDashboard or OpenTBL. Other online platforms used specifically for peer evaluation are also available and include CATME, iPEER, SparkPlus, and Teammates (Clark et al., 2018). Considerations for these platforms include the ability to create unique questionnaires, method in allocation of points, evaluation of self and/or teams, flexibility in design to include qualitative and/or quantitative questions, and the ease of "translation" of data for analysis and into LMSs as grades.

Summary

In this chapter, we focused on TBL as an active learning strategy. The historical and theoretical underpinnings of TBL are presented. Uses of TBL in various forms supported by the use of technology are also discussed. The demonstrated benefits in attaining learning outcomes warrant additional research; however, it is clear that TBL develops and promotes teamwork, collaboration, communication, critical thinking, and problem-solving skills.

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The Foundations of Collaborative Programming by Elementary-Aged Children

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Abstract Until recently, collaborative programming in elementary contexts largely involved traditional one-computer pair programming, more commonly used in industry and university settings. This chapter outlines the historical background of traditional pair programming and if and how its use with elementary-aged children holds as much promise. We then explore alternative paradigms, which generally include the addition of a second computer; we call this configuration two-computer pair programming. Harnessing the advances in programming applications that permit synchronized collaboration, we then report on our work with both one- and two-computer pair programming in block-based programming environments. We conclude by providing a summary of student experiences and opinions on the one- and two-computer studies, and a set of actionable guidelines for practitioners who would like to implement these different collaborative paradigms in their elementary computer science lessons and digitally mediated team learning (DMTL) researchers who will develop support features in these types of environments.

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Introduction

Collaboration

At its foundation, *collaborative learning* is when two or more students undertake learning together (Dillenbourg, 1999). Researchers and practitioners have considerable latitude in defining collaborative learning; however, as group size may range from dyads to an entire class, the learning may be proximal or distal, and together may mean physically close to or asynchronously linked. In computer-supported collaborative learning (CSCL) contexts, Dillenbourg (2002) suggests that it is more appropriate for research on collaborative learning to focus specifically on how students interact as well as the affective and cognitive implications of these interactions. He maintains this work can be done by structuring the collaborative process to produce desired outcomes and/or by regulating student interactions. Thus, CSCL research necessarily aligns expertise and knowledge from education, educational technology, and computer science (Järvelä & Hadwin, 2013).

Successful collaboration comprises discussion, shared decision-making, and joint engagement (Roschelle & Teasley, 1995). One of the affordances of a CSCL environment is that these processes can be made more obvious to the participants, practitioners, and researchers alike (Shawky et al., 2014). Learners in a CSCL context co-construct their knowledge and manage their own and others' learning in ways that are often visible, and this can occur through the use of shared displays and discussion that makes learners' thinking conspicuous (Miyake, 1997). Within the discipline of computer science, one of the ways to facilitate collaborative co-construction of knowledge is by using a pair programming approach embedded in a CSCL activity. Traditionally, pair programming requires that two programmers work together on a shared activity on a single computer (Williams et al., 2000). However, with advances in functionality of technological applications that support collaboration and team-learning, new conceptualizations are emerging. Both traditional and newer conceptualizations of pair programming will be discussed below.

Understanding Collaborative Processes

Before discussing pair programming, it will be important to understand the foundational collaborative processes that pair programming is supposed to encourage and support. By encouraging students to problem-solve on a joint task, they must consider their different ideas and perspectives, varied strategies they might employ, how to overcome conflict, and the processes involved in collaborative decision-making. The study of computer-supported collaborative processes has resulted in a set of characteristics surmised to define the quality of collaboration, including communication, joint information processing, coordination, interpersonal relationships, and motivation (Meier et al., 2007). We use these five characteristics to explore how different collaborative (pair) programming configurations will impact different facets of collaborative processes in different ways. We briefly outline each of them here.

Communication in a collaborative activity is operationalized as the establishment of joint ideas, expectations, and assumptions as well as the use of verbal and nonverbal cues that signal acknowledgement of ideas, attending to the task and speaker, and transitions involving turn-taking.

Joint information processing is the notion that collaborators have joint and individual knowledge but by incorporating individuals' knowledge, they are better equipped to leverage the resources of one another and to come to a more thoughtful, reasoned consensus.

Coordination is largely how collaborators organize themselves and their work; in particular, it is concerned with how they manage the task, their time, and technical aspects.

The **interpersonal relationship** between collaborators is most successful when balanced, or symmetrical; when socially fractious or otherwise imbalanced, the collaborators can engage in unproductive and off-task conflict.

Motivation refers to an individual's dedication to the task, including focused attention and engendering an effective learning environment.

One-Computer (1C) Pair Programming

Foundational 1C Research

Computer science education literature is replete with pair programming studies. In the classic implementation of this configuration, two programmers work collaboratively on one computer and operate using the roles of *driver* and *navigator* (Williams et al., 2000). The driver makes changes to the code and is in control of the mouse/trackpad and keyboard. The navigator checks the driver's work and looks ahead to scan for problems. Both programmers are expected to talk continuously about their work, collaboratively problem solve, and switch roles after a set amount of time or when a portion of the task has been completed. This pedagogical configuration has been used in industry (Beck, 1999; Canfora et al., 2007), in undergraduate classes (Williams et al., 2000), and in high school (Missiroli et al., 2016). We refer to this configuration as *one-computer pair programming* (1C) because both programmers share one computer.

Universities began to use 1C in their computer science classrooms soon after it was introduced as an accepted industry practice. At the university level, 1C studies have revealed that students had a higher success rate in their classes, performed better on midterms and tests and performed better on projects (Werner et al., 2004; Williams et al., 2002) than students that worked individually. 1C programmers also produced higher quality code than individual programmers (Williams & Upchurch, 2001). Additionally, Werner et al. (2004) found that 1C programming helped to improve undergraduate students' confidence, especially female students, and thus could potentially help with female retention challenges. Although research has documented many benefits to 1C programming, there is evidence to suggest that when one collaborator starts out more knowledgeable than another, the more knowledgeable peer tends to take control, leaving the other partner confused, disengaged, or unhappy (Braught et al., 2010).

Research in K-12 contexts is a more recent contribution. Middle-school 1C programmers not only increased their Alice programming knowledge but did better in computational thinking post-tests than did individual programmers (Denner et al., 2014). Werner et al. (2013) found that when middle school friends are paired together, if one student is more confident than the other, then the more confident student's programming knowledge improves when working with a less confident partner with more prior knowledge. Recently, researchers have turned their attention to deep quantitative and qualitative analyses to understand the pair programming process and the programmers' affective and cognitive states (Celepkolu & Boyer, 2018; Rodríguez et al., 2017; Toma & Vahrenhold, 2018).

Newer Interest in 1C with Younger Students

Newer work on elementary students' pair programming has often focused on their discourse and collaborative processes. In an early study of an interdisciplinary activity with younger students using programming and knowledge of science topics, such as the human brain, Kafai and Ching (2001) found that when upper elementary students were planning and designing a science website, they engaged in discussions of scientific concepts more when designing screens. They also found that students who had more experience in software design contributed more to discussions about the scientific topics within the context of design.

Other researchers that have taken a closer look at younger students' collaborative processes have found that, on average, pairs of Latino/a students used more nonverbal behaviors than pairs of Caucasian students (Ruvalcaba et al., 2016). The equity of a collaborative relationship depends in part on how the individuals' goals align (Lewis & Shah, 2015) and the way the students position each other socially (Shah et al., 2014). Elementary students often engaged in both problem-specific discussions (Baytak & Land, 2011; Israel et al., 2017) and discussions of their achievements, as well as more general off-topic conversations (Israel et al., 2017). Problem-specific questions involved talking through the problem (Israel et al., 2017), asking for help (Baytak & Land, 2011), and exchanging ideas (Baytak & Land, 2011). In a study with younger children, Fessakis et al. (2013) found that the students' class interactions fell into one of five categories: competition, interference concerning command proposals and instructions, collaboration, moral support, or dialogue development among the rest of the children.

Challenges to Using 1C

Lewis and Shah (2015) and Shah et al. (2014) analyzed the frequency of the students' communication with one another as well as the content of their discussion. The authors investigated four pairs of students with one student, Jason, as a student in all pairs. Two of his collaborative relationships were more equitable than the other two. As a result, the authors reached the conclusion that equity in a collaborative relationship may be contextualized based on the lessons students are working on, and some students' desire to complete projects quickly may lead to inequitable relationships. Their curriculum was self-paced and may have contributed to students' focus on completing the projects quickly.

In a study of equity in 1C, researchers analyzed how a pair of girls in a high-school elective on the topic of digital making positioned themselves via speech and computer usage (Deitrick et al., 2016). The analysis leveraged positioning theory (Van Langenhove & Harré, 1999), in which the roles of agents (students) interacting with one another are considered fluid and are changed according to the interaction. The study of girls' collaboration found that one student established herself in a more knowledgeable and authoritative position by speaking more, giving commands, and maintaining control of the equipment (Deitrick et al., 2016).

In brief, these studies indicate that traditional 1C can be problematic because it can lead to inequitable relationships and conflict. Tsan et al. (2019) found that upper elementary students in 1C activities often displayed a series of conflicts, which mostly revolved around implementation of ideas, turn-taking, and other equipment issues. However, these noted challenges open up opportunities for a reevaluation of using 1C to explore alternative paradigms.

Collaborative Processes in 1C

Meier et al. (2007) framework can be used to summarize how both technology and student age can shape the patterns of collaboration in a 1C pair programming environment.

Communication

Pair programming in a 1C configuration requires that both programmers communicate continuously and effectively. When executed appropriately, both programmers employ varied strategies to acknowledge each other's contributions, such as verbal utterances, establishing eye contact, using gestures, such as head nodding, or following each other's suggestions. Levels of communication may differ by age. In fact, Tsan et al. (2018) found that most elementary 1C programmers do not verbally acknowledge their partner's contribution.

Joint Information Processing

The sharing of information is essential in any collaborative task. In 1C, information sharing may be complicated by the fact that only one programmer is in control of the input devices and therefore seemingly in charge of final coding decisions. Moreover, resolving conflicts or coming to consensus on next steps is challenging for young students who do not often have the social skills and experience to settle disagreements on their own.

Coordination

How students plan and manage their time and task components is important for any pair programming activity. In a 1C configuration, coordination may look like outlining which tasks need to occur first and which programmer/driver will accomplish what. With timing, external controls (e.g., a clock) are often used to enforce switch points.

Interpersonal Relationship

A 1C configuration has the potential to exacerbate an imbalance in a pair's relationship as many young programmers prefer the driver role to the navigator role, often resulting in diminished interactions on the navigator's side. Control of the preferred driver's role can thus be utilized as an exercise in power.

Motivation

Maintaining motivation toward any activity is important for programmers to elicit learning gains. In 1C, maintaining motivation may be problematic for the navigator as young programmers struggle with embracing the importance of this role and effectively adhering to its purposes and expectations.

Alternative Paradigms

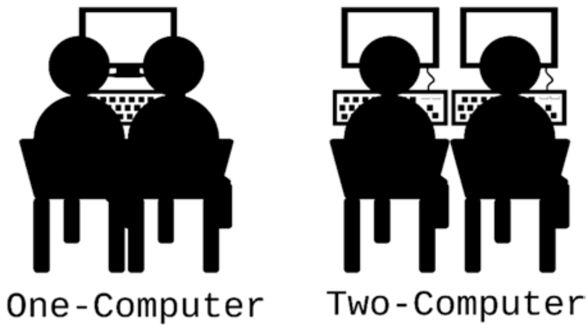
Other researchers have expanded the conceptualization of what constitutes pair programming by augmenting the number of computers being used. In a sixth-grade coding camp, Lewis (2011) compared traditional pair programming with "intermittent collaboration," a condition in which paired students worked on their own computers but were required to sit next to one another, to discuss their work and problems every 5 min, and to assist each other before asking the teacher for help. The *intermittent collaborators* completed their work more quickly and viewed Scratch and programming more favorably than the traditional pair programmers. This collaborative programming configuration is not new (e.g., Cockburn, 2004; Nawrocki et al., 2005; Prechelt et al., 2008). We term this new paradigm as *two-computer (2C) pair programming* (Tsan et al., 2020). *2C pair programming,* or 2C for short, occurs when two programmers each have a computer and (1) each has full, parallel input control and viewing; (2) they are in close physical proximity so that they can talk and gesture, including pointing at each other's computer screens (Fig. 1).

Qualitative analyses of 2C programmers indicate that, although working independently may be the primary mode used because there are two sets of unlinked input devices, pairs engaged one another in conversation for very specific purposes: to combine their work, to share information, to debug the code, or to talk about work strategies or next steps (Prechelt et al., 2008). This fluid and purposeful conversation is possible because of their physical proximity. Cockburn (2004) supported this physical separation of 2C programmers, noting that traditional pair programming left drivers feeling watched by the navigators and with minimal time to work on other tasks. In a study with upper level undergraduates, Nawrocki et al. (2005) compared traditional pair programmers to 2C programmers on completion time/effort, familiarity with code, and the programmers' impressions with their programming condition. Seventy percent of programmers said they preferred 2C programming.

Dewan et al. (2009) put further separation between programmers by introducing the idea of distributed 2C programming. Here, programmers worked remotely but each had a second *awareness computer* that displayed their partner's real-time progress. The authors describe distributed 2C programming as a superset of solo and traditional pair programming in that participants can choose to program individually, as a driver or navigator, or alongside their partner.

A recent contribution to the field is *distributed computing*. A programming environment such as NetsBlox (Broll et al., 2016) permits this type of collaborative work. It is a visual block-based programming platform designed to teach younger students and other novices distributed collaborative computing. Students can invite collaborators—other learners from within the same classroom to others around the world—to help create content, and the code updates on one screen appear in rapid succession on the other. This type of synchronous distributed computing removes

Fig. 1 One-computer and two-computer configurations



the need for "awareness computers" and permits students to collaborate wherever there is an internet connection.

Two recent studies that use NetsBlox in a distributed 2C configuration with upper elementary students show promise in structuring young programmers' experiences with block-based applications. Zakaria et al. (2019) found that this configuration could lead to cooperative work, rather than collaborative work. Cooperative work is that which occurs in tandem and is typified by students dividing tasks to be completed individually, whereas collaborative work is premised on the interdependence of students who complete work together (Hathorn & Ingram, 2002). Bradbury et al. (2019) summarized multiple studies and revealed that upper elementary students largely preferred the 2C configuration and that students perceived they learned more and had more hands-on experiences in this configuration.

Lytle et al. (2020) investigated three collaboration modes with middle- and high-school students' distributed 2C experiences with NetsBlox. The authors designed and compared three conditions: Pair-Separate, Pair-Together, and Pair-Puzzle. In Pair-Separate, the students work in the same project file but have separate tasks and code to complete. In Pair-Together, the students work in the same project file but have access to all code and have editing rights to their partner's script. In Pair-Puzzle, the students work similarly to Pair-Together although each student has a specific set of code blocks necessary to complete the task. Results indicate that students overwhelmingly preferred the Pair-Puzzle condition as the mutually dependent nature of this mode prompted students to talk with regularity and know that their limited blocks would result in the correct code.

Although not in NetsBlox, Deng (2017) further investigated how different collaboration models affect the collaboration process with undergraduate students. Deng implemented three collaboration models in MIT AppInventor, a block-based programming environment where users can create Android apps. The collaboration models were project-level collaboration (only one user can edit the code at a time), component-level collaboration (only one user can edit each component or set of blocks at a time), and real-time collaboration (any user can edit anything at any time). The author found that the real-time collaboration model yielded shorter turns and the lowest mistake rate. The component-level collaboration model yielded the lowest communication level and highest mistake rate. The project-level collaboration model yielded longer turns and the highest communication rate. Lytle et al.'s (2020) Pair-Separate and Pair-Together are most similar to Deng's (2017) component-level collaboration and real-time collaboration models, respectively. These collaboration models can also be implemented in NetsBlox for further research on how they affect students' collaboration processes.

Linked and Unlinked 2C

In our research, we have employed a number of collaboration coding taxonomies and analytic techniques to explore the interaction of configuration and pedagogy and how they might optimize Meier's categories. The review of CS education literature outlined above provided examples and inspiration for 2C programming configurations that could be explored in our own work.

For our work, we have two versions of 2C: *linked* and *unlinked*. For *Linked 2C*, the students work in a synchronized, shared development environment in the same project (like in Google docs). We investigated linked 2C programming by providing each child with a computer and synchronizing their workspaces over the web using the NetsBlox programming environment (Broll et al., 2016). For *Unlinked 2C*, the students do not have a shared development environment and each of them have a different copy of the project. This structure leads to dynamics that are similar to a 1C configuration with students communicating about their work, offering suggestions, and exchanging control of code, even though the driver/navigator roles are not strictly enforced.

Collaborative Processes in 2C

Most of the older studies noted previously emphasize adult students—with a few focused on intermediate programmers who were CS graduate students—and this work was only done with text-based languages. The more recent shift toward exploring how young students might benefit from a 2C programming context and use of block-based programming environments indicates elementary students may be more satisfied with 2C programming; however, they often work cooperatively rather than collaboratively, and more research is needed on the best way to leverage 2C programming and how we can build adaptive support features to help them. Here, we outline how Meier's framework can summarize elementary students' collaborative processes using 2C programming.

Communication

Pair programming in a 2C configuration requires effective communication between partners because the two programmers, with their individual workspaces, can work on different aspects of the programming activity. Therefore, they must verbally apprise each other of their thinking and actions in order to not impede individual and group progress. In an unlinked 2C configuration, this communication may be all the more vital as the two programmers do not have visual awareness of each other's coding actions.

Joint Information Processing

In 2C, sharing of information could be reduced if both programmers are able to edit the code. Students may exchange ideas less frequently during 2C and a teacher or system intervention may be necessary to help students have successful 2C interactions. In an unlinked 2C configuration, consensus may be less critical as the two programmers have the ability to make individual decisions. In a linked 2C configuration, consensus is necessary for both programmers to feel that their contributions to the common code are valued.

Coordination

Coordination is essential for the success of 2C implementation because the increase in input devices likely enhances the need for systematic actions. With the linked 2C configuration, students will need to decide who is editing which parts and when. Otherwise, they will likely encounter editing conflicts in the code and become confused about the output (Bradbury et al., 2019). In this linked environment, students may resort to a quasi-cooperative mode where they work in parallel on separate parts of code. In an unlinked 2C configuration, pre-task planning may help programmers determine how to chunk tasks by time. Additionally, if they are creating the exact same project in both workspaces, it may help ensure that they are both making the same edits in their workspaces.

Interpersonal Relationship

There is potential for programmers to maintain a more symmetrical interpersonal relationship balance in 2C because they can express individual autonomy through their individual workspace. This symmetry may vary by linked and unlinked configuration; however, in unlinked, the need to maintain a symmetrical relationship, although desired, is less imperative because the programmers can complete individual tasks.

Motivation

Maintaining motivation in a 2C configuration may be markedly different from that which occurs in 1C. The value students ascribe to their role and the contribution this role makes can shape motivation. In 2C, programmers have the opportunity to directly construct and edit code if they so choose. With linked 2C, students also have the option of assuming the navigator role as done in 1C and, for that reason, there is still the potential for one student to move into a more passive role, disengaging while the other student completes the tasks at hand. In that way, it is still important to maintain motivation for students using linked 2C as there is for students using 1C.

Current Work: 2C

Study Contexts

In the work done by our team described in this section, the students experienced a curriculum that covered concepts such as algorithms, conditionals, loops, broadcasting, and user input. As part of this curriculum, the students were taught about both 1C and linked 2C programming. They were introduced to the roles and responsibilities of the driver and navigator in 1C, and they were taught about the importance of talking through their decision-making process in both configurations. The teachers shared digital posters for both 1C and 2C (modified versions presented in Fig. 2) or had printed versions of the posters that were placed in front of the students and reminded students of how they should work in each configuration. Our studies took place in two suburban fifth-grade classrooms at Clark and Frederick Elementary (pseudonyms). All students experienced 1C and 2C. We alternated the programming paradigm for every lesson.

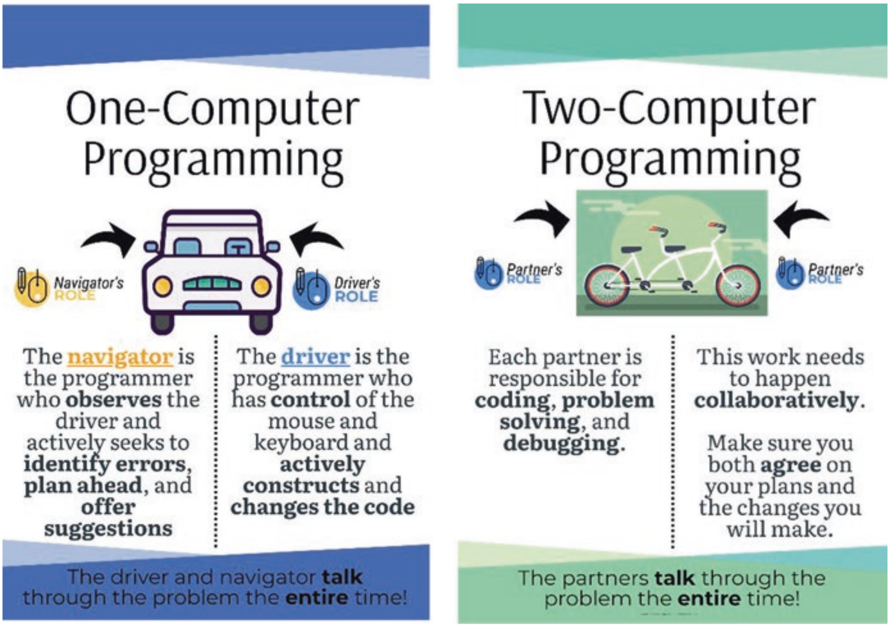


Fig. 2 Posters of one-computer and two-computer pair programming instructions

Collaborative Regulation of Learning

At Clark Elementary, 68 fifth-grade students participated in the study (29 girls, 39 boys). The students, paired according to the teacher's perceptions of the students' prior collaborative behaviors, were taught the coding lessons by the school's media center teacher during the students' dedicated weekly media special. Students used both 1C and 2C programming and were video recorded each time they programmed. Videos were transcribed verbatim and annotated using a multidimensional coding scheme based on collaborative regulation of learning (Janssen et al., 2012) and how students' discourse indicated they were working together (Kumpulainen & Mutanen, 1999). Table 1 is a modified version of this framework.

Over the course of the study, there were noticeable differences by 1C and 2C configuration in how students spoke to each other. Overall, on 1C days, students uttered more *Monitoring*, *Agreement*, *Collaboration*, and *Confusion* statements than on 2C days, whereas on 2C days students uttered more statements tagged as *Planning* and *Evaluation*. However, we found that students' discourse was drastically different from the initial 2 days of the study compared to the final 2 days; regardless of configuration, on the final days, students uttered more *Confusion*, *Disagreement*, and *Individualistic* statements compared to the first 2 days.

Table 1 Modified collaborative regulation of learning framework (based on Janssen et al., 2012; Kumpulainen & Mutanen, 1999)

Dimension	Code	Definition	Examples
Task regulation	Planning	Discussion of the task, how to complete it, deciding which strategies to employ, responsibilities students will take on	Let us start by picking a background
	Monitoring	Discussion of performance and progress, specific mention of strategies being used to approach the task, mentions of time	The glide block would work better last time, so let us try that
	Evaluation	Review of performance and progress, includes appraisals of task difficulty	That was harder than I thought it would be
Social	Collaborative	Actively engaging with partner, attempts to maintain symmetrical contributions	Let us change it so she says "hello" for longer, don't you think?
	Agreement	Acknowledgements and affirmations, most often in response to a partner's contribution	Oh yeah! Yes
	Tutoring	Asking for or offering help/assistance	Hey, how do I add another sprite?
	Disagreement	Social or academic conflict	I will delete it if you write that in there
	Confusion	Failure to understand the partner or the task, often accompanied by a question	That is not what I was thinking
	Individualistic	Working independently with no clear attempt to involve the partner	(These examples often looked like self-talk in proximity to another)

When we consider Meier's collaborative processes as demonstrated here, we found that there was a unique interaction between configuration and time. In the first 2 days, students communicated effectively, largely coordinated their efforts well, maintained their **motivation** and an appropriately balanced **interpersonal relationship**, and successfully engaged in **joint information processing**. However, on the final days, the students, not having developed a sense of competence in either the programming environment or configuration, struggled, leading to confusion, disagreement, and more individual work. Their **interpersonal relationships** were unbalanced and contentious, leading to ineffective **communication** and a lack of **joint information processing**.

Investigating Types of Talk

At Frederick Elementary, we worked with a gifted classroom comprising a total of 11 students who were taught by one of the authors about both 1C and linked 2C programming. We utilized a coding scheme aligned with Mercer's original IDZ (2000) framing guided by T'sas' (2018) articulation of Mercer's three talk types (Exploratory, Cumulative, and Disputational) to code student transcripts (Table 2).

Using time interval coding (Bakeman, 2000), we found that, overall, students used Cumulative conversation more than the other two categories in both 1C and 2C configurations (Fig. 3). There were no significant quantitative differences in types of conversation between 1C and 2C; however, we had three interesting qualitative observations: first, in 1C, challenging ideas resided primarily with the driver while the navigator was left defending their ideas. Second, instances of Exploratory conversation were often preceded or followed by Disputational in 1C, whereas it transitioned into Cumulative conversation in 2C. Finally, evidence suggested that 2C has the risk of collaborative relationships devolving into cooperative relationships,

Table 2 Combination framework for types of talk (based on Mercer, 2000; T'sas, 2018)

	Exploratory	Cumulative	Disputational
Major characteristics	Challenge, alternative hypothesis, critical reasoning	Uncritical addition of ideas, agreement	Disagreement without critical reasoning
Elaborated characteristics	● Offered alternative hypothesis ● Initiations challenged, and counter-challenged followed by consensus ● Justifications given ● Joint acceptance	● Agreement without critical discussion ● Friendly and conflict avoidance ● Positive but uncritical adding of ideas ● Superficial amendments	● Disagreement without outcome ● Individualized decision-making ● Initiations directly rejected ● No/little constructive criticism ● Counter proposition with no consensus ● No resolutions

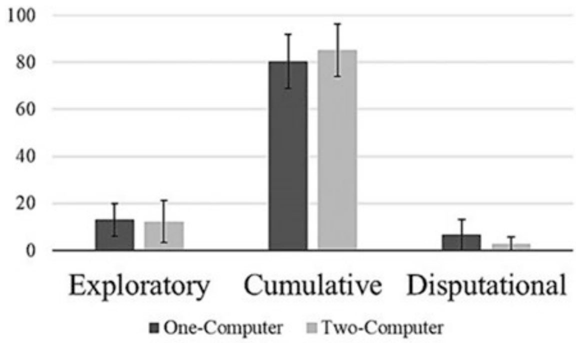


Fig. 3 Percentage of each type of talk per minute, by configuration

where students worked parallel rather than focused on the same immediate task (Davidson & Major, 2014). However, partners still consulted each other regularly and had a balance of opportunities to challenge and explain their thoughts to each other in 2C.

In this work, we focused on students' **communication** with a focus on the types of talk that were used by the students. Although there were not any differences with types of talk, there were differences in patterns of talk between 1C and 2C pairs. There was also a difference in how they **coordinated**, how much they **communicated**, and whether they used **joint information processing**.

Unlinked 2C

The prior studies indicate that a linked configuration helped shape students' collaboration. As a point of contrast, we now report on an unlinked 2C configuration study. We selected six dyads, three from each condition, based on the video and audio clarity. Dyads created identical programs on each of their computers. Students in the feedback condition received structured feedback on key characteristics of Exploratory talk (i.e., *challenging partners with questions, sharing alternative ideas, justifying ideas, or disagreements*).

To better understand how Mercer's (2000) three types of talk are formed in a pair programming context, we needed more information about conversational categories that would combine into these types of talk than the aggregated scheme used in "Investigating Types of Talk" had provided. This abbreviated coding scheme is presented in Table 3.

The findings suggested that, overall, collaborative talk was significantly higher in dyads who received feedback and instruction. The most important indication of this study is that nearly all of the Exploratory categories (*alternative idea, justification, disagreement followed by justification*) were used at significantly higher rates in the experimental condition, except for *higher order questions*. Instead of *higher order questions*, use of *simple questions*—questions that do not challenge partner's

Table 3 Abbreviated framework for types of talk

	Categories	Description	Examples
Cumulative	*Simple question*	Question about a process or fact (any type of questions which are not higher order)	"Which one?" "What are you doing?"
Exploratory	*Higher order question*	Questions that challenge their partner's ideas. These questions should be asked for reasoning	"Why did you move it?" "How do you know?"
	Justification	Student justifies their idea, change, or step with reasons	"Five seconds is too long"

ideas—was found to be used significantly more by the experimental condition. Reflecting on the content of the feedback, we believe that our prompts may need clarification on how those questions are different. The findings lead us to examine an intervention that can be utilized to engage students in higher levels of collaboration as exemplified in Mercer's Exploratory talk.

With the 2C unlinked pairs, the students were required to **coordinate** more than the students that used 2C linked pair programming in the previous study. Both students in each pair needed to maintain **motivation** in order to complete the project in their workspaces. Comparing the feedback and control conditions, we found that the **communication** was better with the pairs in the feedback condition. Their communication consisted of a larger percentage of Exploratory talk and *simple questions*.

Takeaways and Conclusions

Summary of Research Findings

Benefits

1C	2C linked	2C unlinked
● More occurrences of exploratory conversation before and after disputational (**communication**) ● Students monitored their work during the task, collaborated and agreed (**communication, joint information processing**)	● Students engaged in more planning (**coordination**) and evaluation (**joint information processing**) actions prior to and after the task ● More hands-on experience than 1C (**motivation**)	● Students were able to each work on their own computer and code (**motivation**)

Challenges

1C	2C linked	2C unlinked
● Students expressed more confusion (**communication, joint information processing**)	● Students often resorted to cooperation, working in parallel, instead of collaboration (**coordination**)	● Context demanded students coordinate through self-explanation to create the same project on multiple devices (**coordination**)
• Waiting to be in the driver role (**motivation, interpersonal relationship**)	● Context demanded students coordinate to prevent coding conflicts (**coordination**)	● Difficulty seeing each other's work (**joint information processing)**
	● Difficulty seeing each other's work (**joint information processing)**	

Summary of Student Experiences and Opinions

To better understand how students perceived their work in 1C and 2C, we held focus groups with students at one of the study sites. The majority of students (12 out of 15) preferred 2C over 1C (Bradbury et al., 2019).

Students reported the following challenges in 1C. One student tried to retain the driver role, which the students preferred to navigating as they did not like waiting to work on the computer (**motivation, interpersonal relationship**). Moreover, students stated that they argued more often because their partner did not listen to them (**communication**, **interpersonal**). Lastly, students felt there was not enough hands-on experience in this configuration (**motivation**), which they clearly valued. In 2C, students largely reported technical difficulties with the two computers not synching quickly which led to a lag in one student seeing what their partner completed (**coordination**, **joint information processing**). Also, students complained of lack of space given that each student had their own computer.

Regarding the benefits of 1C, students reported that they learned more because they could see and help resolve their partner's mistakes (**communication**, **coordination**, **joint information processing**), and that they felt less cramped with only one computer. In 2C, students enjoyed that they each had a computer, leading to more hands-on experience (**motivation**), and that they learned more in this configuration as a result. Additionally, some reported that they cooperatively worked by breaking tasks into smaller subtasks (**communication**, **coordination**).

Set of Actionable Guidelines for Practitioners

Collaborative programming holds promise for advancing programmer confidence, satisfaction, knowledge, and enjoyment (e.g., Maguire et al., 2014; Rodríguez et al., 2017; Tsan et al., 2020). Traditional 1C programming may be better suited for older programmers, whose cognitive and social development better supports turn-taking, verbal scaffolding of a partner, conflict resolution, and joint problem-solving. 2C, either linked or unlinked, may support younger programmers, as such configurations tend to ease concerns about inequity, conflicts over turn-taking, and code implementation, and provide a more direct hands-on experience. Practitioners must weigh the logistical considerations of their classrooms (e.g., seating arrangements, number of devices, bandwidth strength, size of devices) alongside the learning needs and abilities of their students.

Campe et al. (2019) provide a toolkit for practitioners to use in K-12 classrooms when implementing traditional 1C programming. Their toolkit is research-based, gives practitioners suggestions on ways to pair students, and offers activities for enhancing collaboration and communication.

From our own research with upper elementary students, we offer the following final thoughts for practitioners.

- To allow for more student agency, 2C is likely a preferred option. In this configuration, students are encouraged to express their ideas while also negotiating toward a group outcome.
- When practitioners have students who would benefit from hands-on experience, 2C is the preferred option; however, when students would benefit from peer-to-peer learning, 1C may be best.
- Regardless of the configuration, practitioners likely need to support students' communication practices, in particular, with turn-taking and role-playing in 1C and with coordinating individual to group efforts in 2C.

Additionally, we suggest that researchers consider implementing the following software features for 1C and 2C programming.

- Icons of the students who are connected and a way for students to click on the icon to determine which sprite/background their partner(s) are working on.
- Showing the pointers in order to allow the students to gesture on the screen.
- Communication support in the interface. These supports could be in the form of virtual agents or prompts and collaboration scripts to reinforce effective communication between students; in particular, supports are needed to reinforce appropriate turn-taking in 1C, and verbal scaffolding of a partner, conflict resolution, and joint problem-solving strategies in both 1C and 2C.

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Part II
Tools for Facilitating Digitally-Mediated Team Learning

Using Extended Reality to Promote Team Learning

Leanne Coyne, Thayer A. Merritt, and Jody K. Takemoto

Abstract Extended reality (XR) has evolved since the invention of the first XR device in 1839, resulting in the interactive head-mounted displays (HMDs) that are available today. XR is mostly used for gaming, socializing, enterprise, and training, although it has many benefits for education. XR experiences are immersive, may appeal to various learning preferences, and can make impossible learning activities a reality. XR may be particularly beneficial for team learning through shared immersive experiences and by providing a sense of presence for remote group work. As with many new technologies, there are challenges to implementing XR for team learning, including technological and software limitations, problems with comfort for long-term use, cost and accessibility issues, and space limitations. This chapter describes XR and its uses for team learning and explains some of the challenges of implementing this technology for learning.

Introduction

The adoption of extended reality (XR) for teaching purposes has grown over the past 5 years as educators are beginning to recognize its potential for education (Coyne et al., 2019). XR includes virtual reality (VR), augmented reality (AR), and mixed reality (MR) and is usually experienced through a digital head-mounted display (HMD). Educational XR has primarily been used for simulations, where it has demonstrated utility for learning skills such as surgery (Ros et al., 2017). As XR can

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simulate any environment, only one HMD is required for any number of different experiences, which is more cost-effective than one piece of equipment for each activity. Therefore, XR may be particularly beneficial for disciplines where specialized simulation equipment is expensive (Coyne et al., 2019). XR can provide educational experiences that are not feasible in the real world, such as learning from mistakes in disciplines where making mistakes has undesirable consequences (Coyne et al., 2019). Additionally, XR lends itself well to gamification, which could generate more enthusiasm for learning, particularly for those subjects that students find tedious and/or boring. For distance education, XR can provide hands-on learning experiences similar to those experienced by students attending classes on campus (Engage Education Platform, 2019). For team learning, XR offers a way for students to work collaboratively to solve real-world problems, enhancing both face-to-face and distance education modalities (Chang et al., 2016; Coyne et al., 2019). This chapter defines XR, describes the utility of XR for education, explains how XR can promote team learning, and describes challenges facing the use of XR for team learning.

What Is XR?

Definitions

Extended Reality

XR is an umbrella term that includes any combination of real and virtual interactions and human–machine interfaces, such as wearable devices. Milgram et al. described the spectrum from the completely real to the completely virtual as the reality–virtuality continuum (Mantovani et al., 2003; Milgram et al., 1995). If we consider this as a scale (Fig. 1), different XR technologies would sit at different points on the scale, while XR covers the entire spectrum except for reality itself.

The “extended” in XR implies a broadening of the realm of possibilities, allowing us to interact with the world, information, and one another in ways that would not be attainable without these devices. For example, XR allows us to visualize what would otherwise be invisible such as seeing the face of a person in a different part of the world during a video call. XR provides faster access to information, such as reading heart rate from a wristwatch rather than counting beats. Finally, XR also allows us to interact with virtual worlds in ways that are not possible in the real world, such as visiting other countries from the comfort of our living room. All XR technologies, from wearables to VR HMDs, combine reality with virtual information to extend the way we interact with the world.

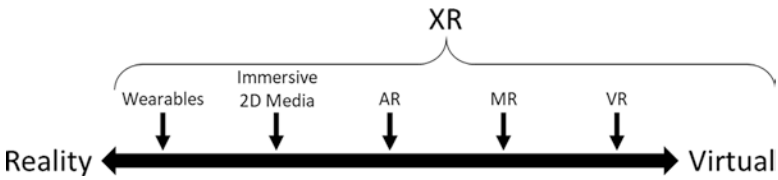

Fig. 1 XR scale from reality to completely virtual environments

Fig. 2 Differences between AR, MR and VR displays

Virtual Reality

VR is at the top end of the virtual spectrum (Fig. 2) and can be considered a completely "…computer-generated simulation of the real or imagined environment or world" (Milgram et al., 1995). Although a completely virtual experience would involve the immersion of all the senses, the most advanced VR experiences currently available provide visual, audio, and kinesthetic immersion through HMDs and haptic controllers. Attachments with olfactory simulations can also be added to HMDs to enable deeper immersion (FeelReal, 2018). VR HMDs are capable of varying degrees of freedom. The most immersive HMDs allow for six degrees of freedom (6DoF). 6DoF HMDs recognize the rotation of the head in all three directions (tilting forwards and backwards, rotating left to right, and tilting sideways) and movement across all three planes (moving forwards and backwards, left and right, up and down). These HMDs provide a "room-scale" VR experience that has a high degree of immersion (Coyne et al., 2019). The Oculus Quest (Facebook Technologies, LLC, Menlo Park, CA, USA) and HTC Vive (HTC, Bellevue, WA, USA) are examples of 6DoF HMDs. HMDs that enable only three degrees of freedom (3DoF) recognize the three directions of head rotation, but not movement on the three planes. 3DoF HMDs cannot provide the same level of interaction with the virtual world that 6DoF HMDs can, but they enable simple immersive experiences and provide a medium for watching 360° videos. The Oculus Go (Facebook Technologies, LLC, Menlo Park, CA, USA) is an example of a 3DoF headset.

Augmented Reality

Unlike VR, AR integrates reality with computer-generated information (Fig. 2) and can be considered a computer-generated overlay of information, such as text and images, on the real world (Foundry, 2016). AR devices do not typically interact with the real world, but allow the user to see the real world and computer-generated information at the same time. For example, Google Glass (Google LLC, Mountain View, CA, USA) was an early example of AR that allowed users to view digital information, such as the internet, maps, and calendars, on a small glass screen worn like a pair of glasses. Newer examples involve phone apps that display information from scanning a QR code or a specific image, and directions provided in real-time by Google maps.

Mixed Reality

MR is similar to AR in that it is an overlay on the real world (Fig. 2), but images on the overlay can recognize and interact with real-world objects (Foundry, 2016). In mixed reality HMDs, users can reach out and interact with virtual objects with their hands. The Microsoft HoloLens (Microsoft, Redmond, WA, USA) is an example of an MR HMD with sensors that enable seamless integration with the real world. These sensors map the surrounding area, which is stored to maintain the persistence of holograms. Mapping data can be stored in the cloud, allowing multiple devices to access the telemetry. When using locally stored data, devices can have user-placed reference points, called anchoring, allowing multiple users to place holograms in the same location on separate devices.

Immersive Two-Dimensional (2D) Media

While VR, AR, and MR are often delivered to users through HMDs, immersive 2D media involves simulated 3D interactions that take place on a 2D screen instead. Immersive 2D media can mimic real-world objects and activities providing a means to interact with computer-generated information. For example, video conferencing software allows face-to-face conversations even when participants are not physically present in the same room. 2D representations of anatomical models can be rotated, enlarged, and virtually dissected to provide a more realistic understanding of the structure and function of organs. Role-playing games such as Second Life (Linden Lab, San Francisco, CA, USA) provide interactive visual and audio information to simulate environments on a computer screen, immersing players in these virtual worlds.

Wearables

Wearables are electronic devices, worn on the body that collect and display information in real-time. Examples include heart rate monitors, GPS trackers, smart watches, and implanted devices such as blood glucose monitors (Happiest Minds, 2020). These devices can provide more efficient and even more detailed information than would be possible without computer interactions. For example, GPS trackers sense the location of a device relative to the world map, which enables easy access to directions or for sharing of information so that progress on journeys can be tracked. Heart rate monitors continuously calculate heart rate, allowing physicians to track a patient's health or an athlete to evaluate their performance. Blood glucose monitors automatically track blood glucose levels, even when a person is sleeping which can help patients make better decisions about diet, exercise, and medication administration.

History of XR

The idea of extending reality with technology has been pursued for over 180 years, starting with VR. The term VR was originally coined in the late 1980s; however as early as 1839, the scientific underpinning of VR began to emerge with the advent of the stereoscope. The stereoscope requires the brain to translate two identical independent images into one 3D image; the conversion of two images to form one 3D image is still the underlying principle of VR today (Pope, 2018). VR has been used in the military since the 1920s with flight simulations used to train pilots (Fedorov, 2015). Around this same time, the View-Master, which required the use of a lenticular stereoscope and images on cardboard disks, was introduced as a children's toy (Pope, 2018). In the 1950s, additional senses beyond vision including sound, smell, and touch were also added to a virtual environment with the construction of the "Sensorama" (Norman, 2020).

Also in the 1950s, AR technology first started to emerge when it was adopted by the military to increase safer flying practices, although the term itself was not coined until 1990 (Poetker, 2019). VR technology progressed rapidly through the 1960s to today, with shifts from large arcade-style theatres to affordable, non-tethered lightweight, standalone, and portable HMDs (Radianti et al., 2020). During this time period, the growth of AR has also been visible through technologies such as the infamous "yellow yard marker" used in football telecasts that indicates where on the field a first down would be located. Examples of the most recent advances in AR technology include smartphone-based applications, such as Pokémon Go, and wearables such as Google Glass, which presents the user with digital information overlaid on the real world (Cipresso et al., 2018). The origins of MR are more difficult to trace but may have been associated with Armstrong Laboratories of the United States Airforce in 1992, which provided training using an MR-like device to enhance task performance (Rosenberg, 1992). MR has continued to evolve over the past 30 years, culminating in the MR HMDs, such as the HoloLens and Magic Leap that are available today (Magic Leap Inc, FL, USA; Microsoft, Redmond, WA, USA).

Current Day Uses of XR and Their Utility for Education

Current day applications of XR include gaming, socializing, enterprise, and training. Many of the ways in which XR benefits these industries can also be applied to education. This section describes several of the current-day uses of XR technology and ways in which it may be leveraged for educational purposes.

Gaming

The most well-known use of XR, particularly VR, is currently for gaming. Aspects of XR games can be extended to education in many ways. Gamification in education can motivate students to learn as games are designed to reward success and have minimal negative consequences for failure (Abrosimova, 2014). Emphasis on reward can encourage students to persevere when they may otherwise have given up. Dr. Karl Kapp identified "engagement" as one of the foundational elements of successful educational game design (Kapp, 2013). The level of immersion afforded by XR could further increase student engagement with educational games (Abrosimova, 2014). Moreover, due to visual, audio, and kinesthetic engagement, remembering concepts in XR games may be easier and deeper than other learning modalities (Abrosimova, 2014).

Socializing

Like gaming, socializing is one of the most popular uses of modern-day HMDs. Social XR allows people to spend time together even if they are not in the same physical location. Socializing in XR provides a sense of being in the same room as other people by providing "a common spatial and social context," (Heidicker et al., 2017). Social XR also provides an opportunity to meet new people in a safe environment. Social gatherings were challenging during the COVID-19 pandemic, but social XR allowed conferences, concerts, and theatre performances to proceed and provided a platform for interaction while maintaining social distancing (Burkhart, 2020; Wheeler, 2020). These types of XR social interactions could be leveraged to improve social presence for distance education, and particularly for distance team learning. In fact, educational social XR platforms such as Engage, already exist and come equipped with all the necessary tools, such as virtual chalkboards, screen-sharing for lecture slides, and even quizzes, to teach remotely in a way that mimics face-to-face education (VR Education Holdings PLC, Waterford City, Ireland). Although social XR HMDs were not commonly used for education during the pandemic, access to these devices could have provided more engaging remote classrooms than the video conferencing software that was primarily used instead.

Enterprise and Training

The use of XR in the business sector has various implications for education. First, several large businesses have begun to utilize XR as part of their workflow. For example, Stryker, a company that builds surgery rooms, has used XR to visualize their designs (MacPhedran, 2018) and the car manufacturer, Volvo, has used XR to improve the efficiency of their design pipeline (Immersive Learning News, 2020). As more businesses begin to adopt XR into their workflow, it is likely to become necessary to train students how to use XR business tools as part of their education. Further, XR is also being utilized by several businesses to better train their employees (Freeman, 2019), potentially setting a standard for XR learning experiences in education.

Using XR for Education

For education, the possibilities of XR are only beginning to unfold. Thus far, XR has been used to develop skills such as surgical techniques, to improve communication, as a visual aid to provide context to literature and to add a sense of presence to distance learning (Coyne et al., 2018; Moran & Woodall, 2019; Real et al., 2017; Samadbeik et al., 2018). XR has also taken students on virtual field trips through space, through the human body, and through history (Knezek & Christensen, 2019; Odlum, 2019; Saunders & Bennett, 2019). Finally, given that the environment in XR HMDs is essentially a 3D canvas, it is not surprising that XR has also been used in education as a tool for creativity and design (So & Lu, 2019). This section describes some of the reasons why XR can benefit education and how it can be implemented, particularly for team learning.

Educational Benefits of XR

Presence and Immersion

The most significant learning benefits of XR technology are from experiences that provide the deepest immersion and greatest sense of presence (Gutiérrez et al., 2007), which are most effectively achieved using HMDs. Having a sense of presence, i.e., how much a person feels like they are truly in and/or interacting with the virtual environment and how real the world in which they are interacting feels (Slater, 2009), in a virtual world can make the difference between an impactful and a mediocre learning experience. Presence and immersion are highly sensitive to hardware and software capabilities, which should be considered when selecting devices for XR learning experiences. For example, it is more likely that a person will feel they are truly interacting with a virtual object if it has high-quality graphics and responds appropriately to the person's actions. Alternatively, poor graphics, latency, and inadequate interactions result in diminished immersion (Gutiérrez et al., 2007). A deeper sense of presence and immersion is afforded by virtual experiences using 6DoF HMDs and 3D sound effects. Scent modules and haptic devices can further enhance the believability of a virtual world by engaging more senses. Haptic devices that provide thermal and/or kinetic feedback when interacting with virtual objects are in development and include full haptic body suits and gloves that provide tension in response to gripping virtual objects (Dexta Robotics, 2018; Teslasuit, 2020). Hand tracking for XR HMDs enables users to interact with virtual objects with their own hands (O-larnnithipong et al., 2019). Although this removes the haptic sensations provided by controllers, it can provide a more realistic experience to interact with virtual objects with one's own hands rather than with a controller. Further, studies have demonstrated that full-body tracking is an important factor in the sense of presence (Skarbez, 2016; Slater, 2009).

A strong sense of presence and immersion in a virtual learning environment is likely to result in improved engagement with learning activities, fewer distractions, and more realistic overall experiences. Perhaps of greatest importance for team learning is the idea of shared presence, i.e., the perception of being together with others in the virtual environment. Collaborative decision-making and team performance is most effective with a strong sense of shared presence, which is crucial for effective team learning (Romano et al., 1998).

Appeal to Different Learning Styles

As XR immerses multiple senses, we can anticipate that learning in XR would naturally accommodate different learning styles. Learning styles can be understood as a learner's preferred method for perceiving and processing information (Kolb & Kolb, 2013). Although there is little evidence that matching learning styles with instructional format improves learner outcomes, accommodating several different learning styles may improve the learner experience (Pashler et al., 2008). In fact, it has been proposed that XR can appeal to all four learning style types (accommodator, diverger, converger, and assimilator) proposed by Kolb (Bell & Fogler, 1997; Kolb & Kolb, 2013). In support of this proposal, a study by Chen et al. (2005) demonstrated that all learners defined by Kolb's learning styles demonstrated improved learning outcomes after a VR learning activity compared to a traditional educational modality of lecture and reading materials (Chen et al., 2005). Similar evidence was found in a study conducted in an elementary school in Taiwan using AR (Huang et al., 2019).

Making the Impossible Possible

Creating immersive learning experiences that encompass various learning styles is not easily accomplished with traditional methods but is possible with XR. According to Oculus, VR can "defy reality" (Oculus, 2020). As virtual environments can be designed to do anything we can imagine, the ability to defy reality is true of all XR. The limitless possibilities of XR have the potential to completely transform the way we teach some disciplines. For example, in many disciplines, learning from mistakes is not feasible, yet making mistakes provides the opportunity to reexamine a situation, identify flaws in the original solution, and try again (Lundquist, 1999). XR can allow students to learn from their mistakes under the guidance of an instructor who can help them improve. For disciplines that are difficult to conceptualize, XR can provide a different perspective that may make it easier for students to learn. For example, students learning about chemistry can shrink to the size of a molecule and see how different chemicals interact (VictoryVR, 2017). XR may also add an element of fun to learning, through interactivity, colorful design, and gamification. Design and creativity can be expanded by the ability to work in a 3D space, as 3D design is far more intuitive in a 3D environment than the 2D environment provided by traditional design tools (Herman & Hutka, 2019). XR has also been used by businesses to train employees by simulating a variety of scenarios that would not otherwise be possible, such as active shooter training (Pecor, 2019).

Using XR for Team-Learning

XR supports team learning in face-to-face classes by providing shared immersive experiences that would not be otherwise possible. For example, Case Western Reserve University developed HoloAnatomy, a platform where teams of students work around a holographic anatomical model and are guided through the systems of the body or virtual dissections (Wish-Baratz et al., 2019). XR can also be used to improve skills such as teamwork, problem-solving, and communication. Scenarios where some students wear an HMD while others guide them through the solution to a problem, as demonstrated by the VR game "Keep Talking and Nobody Explodes," provide a format where important skills such as communication can be refined (Steel Crate Games Inc, Ottowa, Canada).

Many collaborative XR environments, such as SteamVR Home (Valve Corporation, Bellevue, WA, USA) and Engage (VR Education Holdings PLC, Waterford City, Ireland), are equipped with creative tools unique to a 3D virtual environment, such as models and drawing tools (Engage Education Platform, 2019; Steam, 2017). Teams can use these XR tools to drive creativity. A study that compared student perceptions of learning in an interactive XR environment with a social-only XR environment found that students preferred the interactive environment. In particular, students highlighted the usefulness of being able to draw in 3D (Takemoto et al., 2019). Another creative application of XR is for 3D design. 3D design tools, such as Oculus Medium, enable student teams to design and develop

3D models from within XR (Facebook Technologies, LLC, Menlo Park, CA, USA). Some platforms, such as Gravity Sketch, also enable cross-platform use (Gravity Sketch Limited, London, UK), which could allow some students to design models from a tablet while other members of their team view the 3D product from within XR.

Collaboration and communication go hand in hand. Previously, learners needed to be physically together to effectively collaborate on a project. Over time, distance communication became possible through learning management systems, message boards, chat, and video conferencing (Workman, 2018). However, team learning at a distance can still be challenging; students may find distance learning isolating and may struggle to maintain their attention (Kear, 2010; Mukhtar et al., 2020). However, the flexibility of online learning, particularly for unexpected circumstances such as the school closures due to the COVID-19 pandemic, warrants investment in strategies that optimize team learning at a distance. Current distance learning systems are also limited because online lessons often only involve lectures (Kohsaka et al., 2002). XR can immerse learners in a variety of 3D environments, from classrooms to laboratories, operating rooms, and even space, which could encourage instructors to explore more engaging lesson plans (Boyles, 2017).

As previously described, immersion and presence are important for learning, and team learning is most effective when there is a shared sense of presence (Gutiérrez et al., 2007; Romano et al., 1998). Students in distance learning classes often experience a poor sense of shared presence (Kohsaka et al., 2002). Realistic environments combined with realistic avatars and animated projections of team members contribute to the sense of shared presence through facial expressions, voice inflections, and body language (Kohsaka et al., 2002). Further, providing learners with realistic interactions with people, places, and objects can help provide clarity for learners, evoke emotional responses, and provide a variety of perspectives, even at a distance (Coffin et al., 2010; Marr, 2020). In support of this, research has demonstrated that immersive XR environments enable team-interaction that feels enough like face-to-face learning that students forget about their surroundings and would choose XR over other online team learning methods (Coyne et al., 2018). It has been proposed that "inexpensive, smartphone-based XR," will be the future of distance learning (Pomerantz & Rode, 2020). As the popularity of online learning and XR continue to increase, and as technological advances are made and accessibility improves, many students may one day be able to attend classes through a virtual campus with their classmates (Chang et al., 2016).

Implementing XR for Team-Learning

The first step of implementing XR for team learning is to consider what content or activities would benefit from incorporating XR technology and to determine the most appropriate form of XR. For example, will these activities be best achieved with XR HMDs or could more cost-effective immersive 2D media work just as well? The next step is to find out if XR software already exists that can address the needs of the content or activity. App stores such as Steam (Valve Corporation, Bellevue, WA, USA) and the Oculus store (Facebook Technologies, LLC, Menlo Park, CA, USA) may be the easiest place to search for existing applications (Steam Store, 2021; Oculus Apps and Games, 2021). There are also organizations dedicated to the implementation of XR in education such as XR in learning and the VR/AR Association that may be able to provide guidance on existing educational software (XR in learning, 2018; VR/AR Association, 2015). For instructors looking to simulate face-to-face classes using XR technology, platforms such as Spatial (Spatial Systems, Inc, New York City, NY, USA) and Engage (VR Education Holdings PLC, Waterford City, Ireland) provide various interactive tools that can be used to teach students (Spatial, 2021; Engage Education Platform, 2019).

In the absence of available software, instructors may need to outsource or create content themselves. Although developing XR content seems daunting, there are tools available that can help. For example, sandbox applications such as Anyland (Philipp Lenssen and Scott Lowe, Germany and UK) may help non-developers create rudimentary learning activities. Facebook (Facebook Technologies, LLC, Menlo Park, CA, USA) is currently beta-testing a new sandbox application that allows users to build and share interactive VR experiences easily (Anyland, 2021; Facebook Horizon, 2021). For instructors who are more confident with development, the game engine Unity© (Unity Technologies, San Francisco, CA, USA) provides free tutorials on getting started with XR development and has an extensive online community that can provide advice and guidance (Unity Learn, 2021; Unity Forums, 2021). Finally, once equipment and software have been acquired, conducting a trial lesson with colleagues can help identify potential issues that may come up and allow optimization prior to going live with students.

Challenges and Barriers to Implementing XR for Team Learning

The benefits and potential uses of XR for team learning are numerous. However, this technology is still relatively new and has various challenges that are yet to be overcome. This section will discuss some of these challenges, including technology and software limitations, cost, accessibility, and space requirements.

Hardware Limitations

Wearing an HMD for prolonged periods can be uncomfortable. HMD weight and size, visual display quality, heat generation, and the presence of a cable connecting to a computer are all factors that can influence comfort (Evans, 2019; Mehrfard et al., 2019). Additionally, simulation sickness is a possibility for many people with HMDs. Simulation sickness is thought to involve discrepancies between visual information informing the body of movement through the HMD and the actual proprioception experienced by the body (Ng et al., 2020). Symptoms of simulation sickness, including nausea and cold sweating, can be incredibly uncomfortable and usually do not go away until the HMD is removed (Gavgani et al., 2017). Correct alignment between visual information displayed in the HMD and actual movement reduces the likelihood of simulation sickness (VRScout, 2016). Evidence also suggests that experience using HMDs can build up a tolerance to simulation sickness, even with the most high-intensity XR experiences such as VR rollercoaster simulations. Simulation sickness may therefore become less of a problem over time. As the real world is still visible through MR HMDs, simulation sickness is less likely than with VR HMDs (Gruteser & Sani, 2017). A study of simulation sickness in the HoloLens found that symptoms were negligible and limited to oculomotor discomfort (Vovk et al., 2018).

Many HMDs for XR are large and heavy, with a limited battery life or cables that may interfere with function and potentially cause a trip hazard (Khor et al., 2016). MR devices may also have a limited field of view (FoV) that may impede immersion. For example, the HoloLens 2 has an FoV of 52°. Although this is a big improvement from the HoloLens 1, which had an FoV of only 34°, it is still far from the FoV of 110° afforded by Oculus VR devices (benchmarks.ul.com, 2020; Kościesza, 2020). With advances in software and hardware, future improvements in educational XR experiences are expected. For example, Facebook recently released information about an experimental new lens type that allows for a display less than 9-mm thick (Peters, 2020). With further development, this new technology could lead to smaller and lighter HMDs, making comfort less of a limitation of XR for education.

Software Limitations

Depending on discipline, academic level, and the depth of immersion, the availability of educational software is inconsistent. For example, there are numerous virtual field trips available that are useful for K-12 students, but there are far fewer activities available for engineering students in higher education. Developing specialized software is not feasible for most educators and hiring professional developers is likely to be expensive. Although more educational-focused content is becoming available from companies like Victory XR (Victory XR, Davenport, IA, USA), creating custom lessons still requires a basic level of programming expertise.

Cost and Accessibility

In addition to hardware and software limitations, acquiring XR equipment may be challenging for many schools and colleges due to cost. Cost will heavily depend on the type and quality of equipment as well as organization wide management capabilities, which will also impact the breadth and depth of experiences available. The best quality VR and MR equipment can cost thousands of dollars and often also requires a powerful computer to function, making them out of reach for most educational institutions (Coyne et al., 2019). Smartphone-powered VR HMDs are inexpensive, but this coincides with a lower quality, less immersive, and less interactive experiences (Robertson, 2019). Further, these HMDs have a higher chance of inducing simulation sickness due to their lower visual quality and visual-vestibular mismatch from 3DoF-only tracking systems, which could discourage adoption (Ng et al., 2020). The cost of VR equipment has decreased significantly over the past 5 years (Coyne et al., 2019). The most versatile consumer level XR HMD currently available at the time of this publication, the Oculus Quest, costs around $300, provides room-scale VR experiences, and does not require a separate computer (Facebook Technologies, LLC, Menlo Park, CA, USA). This HMD provides a lower cost alternative to high-end devices without compromising the quality of the experience (Greenwald, 2019). As technological advancements are made, equipment is likely to become more affordable. However, most students are unlikely to have their own devices at this point in time, leaving the cost burden on educational institutions. Purchasing enough HMDs for all students would be incredibly expensive. Instead, schools and colleges that do invest in equipment are likely to have several dedicated devices, much like the shared computers that were available in schools during the 1980s and early 1990s (Howson, 2020). This shared equipment would provide some access but would also come with space and capacity limitations. For MR, there are few low-cost HMDs available, but AR activities using smartphones and tablets and immersive 2D experiences can provide cheaper alternatives and may be sufficient for some experiences (Papachristos et al., 2017). Additionally, ZapBox, a smartphone powered cardboard HMD, provides MR experiences for less than $30 (Zappar Limited, London, UK). Overall, it is important to consider what type and level of equipment are needed for the type of educational activity intended. For example, a highly immersive engineering simulation for engineering majors may require high-end equipment for the best learning experience. However, for elementary school students learning to identify anatomical structures in the human body, immersive 2D media may be sufficient.

Institutions that do have the budget necessary to purchase equipment for their students also have to consider the associated management costs. Computer-based software can often be deployed and updated locally through software publishing tools; however, mobile devices, such as the Oculus Quest, require a nonconsumer purchase to have access to device management and deployment tools (Facebook Technologies, LLC, Menlo Park, CA, USA). Microsoft HoloLens, while a much more expensive device on its own, has similar configuration and management options to a Windows-based computer as part of the regular cost of the device (Microsoft, Redmond, WA, USA).

Another cost- and accessibility-related issue that may limit XR use for team learning is internet access. Broadband internet access is not evenly distributed across the world, or even across individual countries (Internet Society, 2017). The need for an internet connection for XR use depends on the type of learning experience. Many face-to-face XR lessons may not require an internet connection, but collaborative XR applications would not function without internet access. Remote synchronous team learning would also be extremely challenging without an internet connection.

Accessibility for XR learning may be limited for people with some disabilities. Currently, most activities in XR rely on visual and audio stimuli, limiting the use of these technologies for the visual and hearing impaired. Some research has been conducted into improving accessibility for the visual and hearing impaired, but this work is still in its infancy (Chang, 2018; Signia, 2018). VR and MR often require long periods of standing and maybe even a lot of movement. Standing for long periods of time and lots of movement may not be comfortable or feasible for many students. For a full review of the needs and requirements for people with disabilities when using XR, see O'Connor et al. (2020).

Space Requirements

Even if accessibility improves, it may be challenging for educational institutions to find sufficient physical space to provide immersive XR learning experiences. Interactive XR experiences require, at a minimum, enough space to enable standing and arm movement and many even require users to walk around (HTC Vive, 2020). If there is insufficient space, VR experiences have the potential to result in injury and/or damaged property. This concern is somewhat alleviated with MR HMDs as the real-world is still visible. Nevertheless, as demonstrated by several incidents with Pokémon Go, where some users got so distracted that they injured themselves, even if the real world is visible, injury may occur if sufficient space is not provided (Barbieri et al., 2017). Finding sufficient space may be challenging in educational environments, where empty rooms may seem counterintuitive to efficient use of space. In many classrooms, finding sufficient space may be impossible due to fixed furniture and stadium seating. For distance learning, appropriate space utilization is out of the control of the instructor. To overcome this issue, students should be thoroughly educated on the essential need to create a safe environment for learning in XR, and instructors should be cognizant that finding enough space may not be possible at all for some students.

Other Challenges

In addition to the challenges outlined above, XR technology has not yet been widely adopted in education and may be completely unknown to many instructors. Educators may be reluctant to use new technology in the classroom unless they are comfortable (Porter & Graham, 2016). This reluctance is likely further exacerbated by limited exposure. As consumer adoption is still in its infancy, it is unlikely that most instructors have interacted with XR technology. It may be challenging, therefore, for instructors to recognize potential uses, or even to understand what XR technology is and of what it is capable. Lack of familiarity with XR technology may also lead to confusion over terminology, resulting in limited understanding of the functionality of different XR equipment. For example, immersive 2D media is still occasionally referred to as a VR experience. An instructor looking to simulate a hands-on experience may overlook VR as an option if they believe that VR is limited to a 2D computer simulation with limited sensory immersion. Similarly, an instructor that is familiar with cellphone-based AR games may not recognize the potential uses of an MR HMD. Familiarity will increase as consumer adoption grows, improving the likelihood that instructors will recognize potential uses for XR technology in education.

The consequences of long-term XR use are difficult to determine. A recent news article about a daily VR user experiencing eye problems highlights the need for further studies to evaluate the impact of XR use on health (BBC, 2020). Additionally, it is unknown if gaming disorder (addiction to video games) can be exacerbated by XR technology (Coyne et al., 2019). The impact of XR technology on social development is also unknown, but students who are shy may prefer to hide behind the comfort of an electronic display. While this may encourage them to interact more readily in a virtual setting, it may limit the growth of communication skills (Chen & Peng, 2008). These unknowns require further research to be fully understood. Nevertheless, XR has the potential to greatly benefit team learning. Over the next few years, as technology improves and current limitations are overcome, using XR for team learning will likely become more appealing and adoption is likely to grow.

Conclusion

XR has been gradually refined over 180 years and includes any technology that combines reality and computer-based information, from wearables to VR HMDs. Modern-day XR devices are predominantly used for gaming, socializing, enterprise, and training, but they are starting to gain traction in education. Indeed, XR devices could provide many benefits for education. Learning is most effective when it is immersive and engaging, which XR technologies can provide. XR immerses multiple senses, which naturally accommodates different learning preferences, potentially appealing to a wide cohort of students. XR learning activities can be designed to do almost anything, significantly broadening the toolkit of educators. For team learning, XR provides shared immersive experiences and social environments that can be particularly beneficial for distance education.

Implementation of XR for team learning requires careful planning. Instructors planning to use XR in their course will need to address common barriers to implementation, such as hardware limitations, cost, accessibility, and space requirements. Additionally, there may not be existing software for specific educational content and instructors may need to consider designing content themselves, or hiring professionals to custom build software for their course.

Overall, despite the current challenges facing implementation, XR has the potential to change the face of education in a positive way. As devices become more widely available and more advanced, many of the current challenges are likely to become less of a problem, and the value of XR for education will be harder to ignore.

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All-in-One Team-Based Learning (TBL) Technology: Profiling the InteDashboard Technology Platform

Brian O'Dwyer

Abstract Team-based learning (TBL) can be used as a specific form of digitally mediated team learning (DMTL) which involves pre-class preparation, individual and team readiness assurance tests, application exercises, and peer evaluation. The objective of this chapter is to describe the challenge of implementing TBL in physical and virtual classrooms because generalist learning management systems often lack specialized functionalities for TBL. This chapter will describe foundations, principles, and functionalities of an all-in-one technology platform for TBL (www.intedashboard.com) that was developed and commercialized by Duke-National University of Singapore Medical School to overcome these challenges. The platform will be described in relation to the National Science Foundation sponsored Synthesis and Design DMTL Workshop where the platform was showcased in 2019. This chapter may help those planning to use, select or develop TBL technology. Limitations and future directions will be discussed.

All-in-One Team-Based Learning (TBL) Technology: Profiling the InteDashboard Technology Platform

The objective of this chapter is to describe the need and solution for the challenge of implementing TBL in physical and virtual classrooms. The introduction will describe TBL, modalities, and the need for specialized all-in-one TBL

The author is the founder of and has a financial interest in CognaLearn. CognaLearn developed www.intedashboard.com in collaboration with Duke-National University of Singapore Medical School which is the technology platform described in this chapter.

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Table 1 Overview of sections "Facilitating Team-Based Learning with Real-Time Online Technologies", "Personalizing Team-Based Learning Through Analytics", and "Supporting Digital Teams Using Active Pedagogical Strategies"

Section	Subsection
2. Facilitating Team-Based Learning with Real-Time Online Technologies	2.1 Activity Authoring 2.2 Student-Facing Delivery 2.3 Instructor Orchestration and Assessment Tools
3. Personalizing Team-Based Learning Through Analytics	3.1 Assessment Mechanics 3.2 Feedback Mechanisms
4. Supporting Digital Teams Using Active Pedagogical Strategies	4.1 Pedagogical Methods for Team Management 4.2 Engagement and Accountability 4.3 Faculty Development

technology. InteDashboard™ (www.intedashboard.com) is an online technology platform for TBL that was developed and commercialized by the author and others at the Duke-National University of Singapore Medical School (Duke-NUS). The first section will conclude with the creation and commercialization of www.intedashboard.com.

Sections "Facilitating Team-Based Learning with Real-Time Online Technologies", "Personalizing Team-Based Learning Through Analytics", and "Supporting Digital Teams Using Active Pedagogical Strategies" will describe foundations, principles, and functionalities of www.intedashboard.com in relation to selected tracks of the National Science Foundation sponsored Synthesis and Design Digitally Mediated Team Learning Workshop (DMTL Workshop) held in 2019 at the University of Central Florida where the platform was showcased. The platform was developed based on feedback from surveys, review sessions, demonstrations, and faculty development workshops with thousands of students, educators, administrators, and technical experts. The chapter concludes with limitations and future directions (Table 1).

The Team-Based Learning Approach to DMTL

The Team-Based Learning Collaborative™ (TBLC) is a global non-profit organization of educators who support TBL (TBLC, 2020). The TBLC (2020) defines TBL as "an evidence based collaborative learning teaching strategy designed around units of instruction, known as "modules," that are taught in a three-step cycle: preparation, in-class readiness assurance testing, and application-focused exercise. A class typically includes one module."

There are over 7000 search results of "team-based learning TBL" on Google Scholar which may have different variations of TBL (Google Scholar, 2020). This

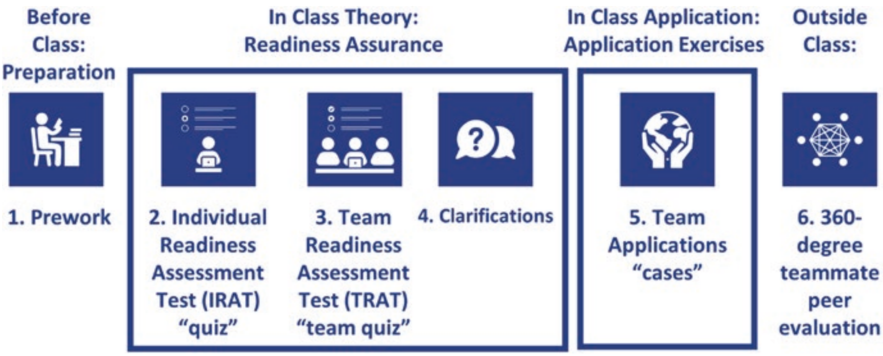

Fig. 1 Schematic of a TBL module. (Source: based on O'Dwyer, 2016)

chapter will consider six components typical of TBL as described below and in Fig. 1.

Preparation Cycle

1. **Prework.** Preparation material in the form of readings, videos, or slide presentations.
   Students are expected to review prework before class.

In-Class Readiness Assurance Testing

2. **Individual Readiness Assessment Test (IRAT).** Class begins with students completing an individual multiple-choice quiz (MCQ) based on the prework. The IRAT typically includes lower complexity items such as basic theory and fact recall.
3. **Team Readiness Assessment Test (TRAT).** Students repeat the same quiz questions in the IRAT but as a team. Team members must agree on a single team answer and receive immediate feedback after each attempt until correct. Teams are awarded full points if they select the correct answer on their first attempt and a declining proportion of points the more attempts it takes the team to select the correct answer.
4. **Clarifications.** Following the IRAT and TRAT, teams are given the opportunity to raise clarifying questions. Educators may clarify any issues of concern. At the conclusion of this step, teams should be equipped with the basic knowledge, skills, and theory to solve more complex problems.

Application-Focused Exercise

5. **Team Application Exercises (Applications).** Teams apply theory to solve relevant problems with "4S" principles of same problem, significant problem, specific choice problem, and simultaneous reporting. These problems tend to be more complicated and applied in nature.

Additional

6. **360° Teammate Peer Evaluation.** Team members complete a 360° evaluation process to rate their teammates. This may not be done after each class, but instead at periodic intervals throughout a term such as every 4–8 weeks.

Modalities of TBL

Modalities for TBL can be categorized based on physical presence and timing synchronicity of in-class activities. Prework is generally done as an individual, independent, asynchronous activity in all modalities. Clark et al. (2018) developed a matrix of TBL modalities which are described below. Additional wording is included to describe "Co-located/In-person" and "Distance/Online/Remote/Virtual" because different terminology is used by various educators, regions, and literature (Table 2).

There is also a hybrid modality. A hybrid modality could include a class that starts with one or two sessions synchronously followed by asynchronous sessions thereafter or a mix of in-person and online students. This chapter will focus on the in-person synchronous and online synchronous modalities because DMTL is focused on synchronous modalities (DeMara et al., 2019).

Table 2 TBL modalities by space and time

		Space	
		Co-located/in-person	Distance/online/remote/virtual
Time	Synchronous	Same physical location at the same time	Different locations at the same time
	Asynchronous		Different locations at different times

Source: adapted from Clark et al. (2018)

The Need for TBL Technology

Robinson and Walker (2008) were some of the first to describe the need for TBL technology and detailed the workload challenges faced by TBL educators and how applying technology could help with some of these challenges. This inspired their development of a TBL technology (Robinson et al., 2007).

Seven years later, the author experienced similar workload challenges with TBL. Although the author had technology support, which included the first-generation version of what is now www.intedashboard.com, the author was still faced with a workload that included 44 steps across six different technology tools (O'Dwyer, 2017). The author's challenge was spending time juggling between different platforms which took effort and delayed access to student and team performance data. The author spent more time managing the TBL process rather than analyzing the data it was generating.

The need for TBL technology will be defined and characterized in four versions of TBL technology adoption. Next, the need for TBL technology will be described in relation to faculty workload, online TBL, and all-in-one TBL technology.

Versions of TBL Technology Adoption

Four versions of TBL technology adoption as described below and in Fig. 2.

- **TBL 1.0 (All Paper):** Only paper-based techniques are used.
- **TBL 2.0 (Some Paper):** A mix of paper and software technologies are used.
- **TBL 3.0 (No Paper):** Multiple software applications are used.
- **TBL 4.0 (All-in-One TBL Technology):** A single all-in-one technology tool is used.

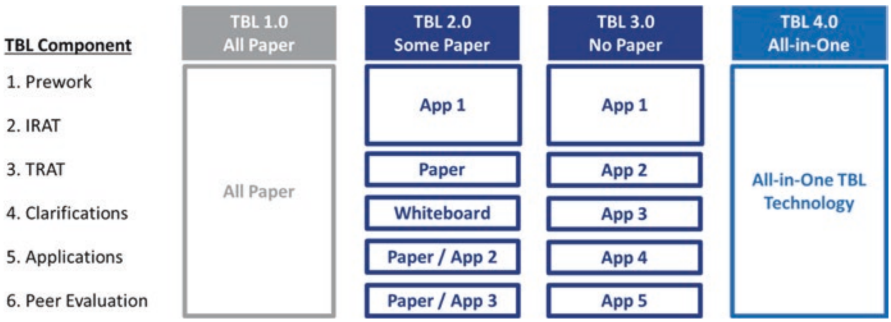

Fig. 2 Versions of TBL technology adoption

Characteristics of TBL Technology Adoption

TBL versions can vary by faculty workload, ability to deliver TBL online, and data availability. The characteristics of TBL versions are described below and in Fig. 3.

- **TBL 1.0:** Highest faculty workload, online TBL is difficult, and difficult or delayed data.
- **TBL 2.0:** High faculty workload, partially online TBL possible, and some data access.
- **TBL 3.0:** Lower faculty workload, online TBL possible, and data spread across multiple systems or delayed.
- **TBL 4.0:** Lowest faculty workload, easiest for online TBL, and real-time data access.

TBL Faculty Workload (Why TBL 2.0)

The author's interest in developing TBL technology was to make it easier for other educators to adopt TBL. The author had observed the benefit of TBL in his class. As a former airline chief financial officer that was teaching airline management, the author felt the TBL process was more like what students would need to do in the workplace. For example, as an airline executive, the author did not need people to sit and listen for hours. Instead, the author needed them to solve complicated problems that involve different functions like maintenance, flight operations, legal, finance, and marketing. Although the author valued TBL, he also found it was a lot of work to implement. As noted below, others have had similar experiences and found that workload can be a barrier to adoption of an otherwise effective methodology.

Literature Reviews. In a literature review of 40 articles about TBL, Haidet et al. (2014) reported benefits from improvements in knowledge acquisition (particularly for students at the low end of the class), team performance, participation, and transfer of classroom learning to job performance. However, Haidet et al. (2014) also

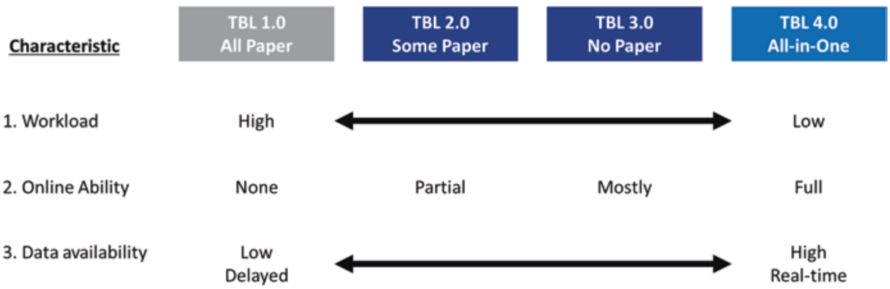

Fig. 3 Characteristics of TBL technology adoption

reported that teachers faced increased workload. In a scoping review of 41 studies about TBL in nursing, Considine et al. (2020) found mostly positive outcomes.

TBL in US Colleges and Schools of Pharmacy. Allen et al. (2013) did a survey with respondents representing 43 institutions using TBL and found workload was a significant barrier to implementing TBL.

Workload models. Two publications describe models for TBL faculty workload. Fitzpatrick et al. (2016) and Brooks and Nelson (2018) described increased faculty workload from TBL.

Faculty Perceptions. Tweddell et al. (2014) studied faculty perceptions of TBL and reported challenges which include increased workload, creating application exercises and facilitation.

The Rise of Online TBL (Why TBL 3.0)

Rise of Online Learning. Online classes have become a meaningful part of United States higher education with 35% of students enrolled in some online courses and 17% of students taking exclusively online class by fall 2018 (National Center for Education Statistics, 2019) which compares to 8% and 2% in fall 1999 (National Center for Education Statistics, 2011) as shown in Fig. 4.

Rise of Online TBL. Like the general trend towards online classes in higher education, there has been an increase in online TBL as well. In 2017, the author was one of the founding members of the TBLC's Online Community of Practice and worked with 16 colleagues on a white paper that identified best practices for online TBL (Clark et al., 2018). Three of the best practices described in the white paper specifically highlight technology as noted in Table 3.

Faculty Development Workshop Responses. In 2020, the author facilitated 14 faculty development workshops for 415 educators on how to implement TBL online. The workshops were delivered in a synchronous online modality using TBL. Workshop participants were divided into teams with an average of five participants on each team. The largest workshop had 108 participants in 15 teams

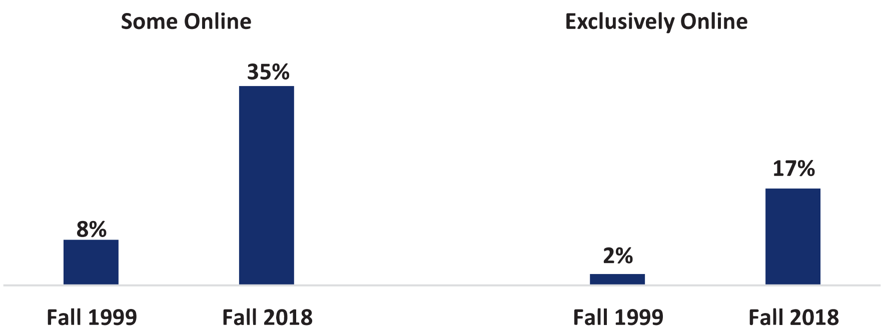

Fig. 4 Percentage of U.S. higher education enrollment in online learning. (Source: based on National Center for Education Statistics, 2011, 2019)

Table 3 Technology-related online TBL best practices

TBL component	Technology-related best practice
Readiness assurance	Use technology and infrastructure to support the RAT design, team interaction, feedback, and academic integrity
Applications	Employ technology to support the chosen application design that promotes collaboration and provides feedback and evaluation of individuals and teams
Peer evaluation	Deploy technology that supports collection, analysis, and dissemination of quantitative and qualitative data

Source: adapted from Clark et al. (2018)

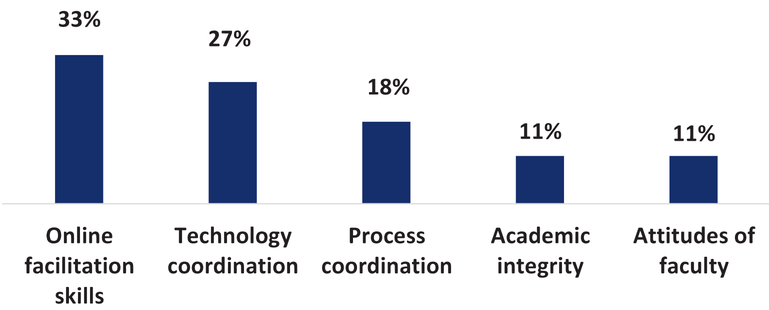

Fig. 5 Challenges with online TBL. (Source: O'Dwyer unpublished data)

and the smallest had 10 participants in 2 teams. The average workshop had 30 participants and 6 teams. One of the team application exercise questions was "what is the biggest challenge you would face in transitioning from an in-person TBL class to an online TBL class?". As shown in Fig. 5, out of 84 teams (excluding 18 responses of "Other"), facilitation skills (33%) and technology (27%) were the biggest areas of challenge.

This reinforces the need for TBL technology as it can make technology coordination and facilitation easier.

Impact of COVID-19 Pandemic. In early 2020, many higher education institutions shifted from in-person to online classes because of the COVID-19 pandemic. This has increased the need for TBL technology as evidenced by the large increase in trials of www.intedashboard.com where there were more new trials in the first 9 months of 2020 than in the previous 24 months combined.

The Emergence of All-in-One TBL Technology (Why TBL 4.0)

Even with a fully digital TBL 3.0 solution, there can be limitations. Just because a solution is fully digital, it may not be the ideal solution for all TBL practitioners. In many TBL implementations, there are several different technology tools being used which are not designed for teams or TBL which creates inefficiencies. These factors contributed to the development of all-in-one TBL technology.

Technology for Collaboration Versus Assessment of Collaboration There are a number of widely available tools for collaboration and group messaging in general such as Zoom, Slack, Google documents, and Microsoft Teams. These collaboration tools can be very useful for students to work collaboratively during TBL. However, their functionality for assessing collaboration in the team readiness assessment tests, application exercises, and peer evaluation is limited or lacking.

Absent an all-in-one TBL system, educators are faced with having to cobble together several different technology tools. One institution identified a specific list of 30 functionalities for TBL. They found they needed a combination of six tools to perform all the functions of TBL. Their learning management system (LMS) could perform about two-thirds of the functions and an audience response tool could perform about one-third of the functions, but there was overlap which left some requirements unmet. The author has experienced personally and consistently heard from many educators that individual components can be done with general LMS technology but that the team assessment elements can be incredibly difficult to implement in a general LMS.

Even the Robinson et al. (2007) system was combined with PowerPoint, file sharing, email, and a word processor. At the time, these five systems were indeed an improvement over TBL 1.0 but still fell short of an all-in-one TBL technology.

All-in-One TBL Technology Availability. While general collaboration technology tools described above are widely available, technology to assess collaboration for TBL is more limited. According to Clark et al. (2018), there are only two "all-in-one TBL systems" which include www.intedashboard.com (the topic of this chapter) and OpenTBL. Sibley, J. (n.d.-b) has listed technology that can help with TBL which shows the same two tools in the "Integrated Online TBL Systems" category. However, OpenTBL, the platform ceased operations in 2018 (Fiderlick, 2018). The TBL software developed by Robinson, Sweet, and Mayrath in 2007 was discontinued in 2012 when one of the key individuals switched institutions.

The Solution: An All-in-One TBL Technology Platform (www.intedashboard.com)

Creation

In 2005, Duke University and the National University of Singapore established Duke-NUS (2020). Duke-NUS has been described as a pioneer in medical education by the Association of American Medical Colleges (2012) for its implementation of TBL across all its basic science curriculum. Kamei et al. (2012) found that Duke-NUS students achieved similar results as US medical students in less time and that after the same time of 2 years, Duke-NUS students performed better than US students. In 2010, Duke-NUS created a web-based software platform to deliver IRAT and TRAT to lighten the TBL workload. This was the first version of what is now www.intedashboard.com.

Incubation

In 2014, as part of a broader effort aimed at the commercialization of research and innovation, the Duke-NUS Centre for Technology and Development (CTeD) hired the author as Entrepreneur-in-Residence to commercialize learning technologies and methods. This resulted in one patent filing which was granted in 2020, and the creation of a new company, CognaLearn, that was founded by the author along with Duke-NUS academics Ranga Krishnan (Dean 2008–2015), Robert Kamei (Vice Dean, Education 2006–2016), and Sandy Cook (Senior Associate Dean) and Frank Starmer (Associate Dean, Learning Technologies 2006–2015). The author left Duke-NUS and became the first employee of CognaLearn while the other founders served in advisory roles and continued with their academic posts.

Commercialization

In 2015, CognaLearn licensed existing technology and a patent from Duke-NUS and began development of a second-generation version of TBL software. The commercialization process had three phases: product validation, need validation, and financial sustainability validation.

Product Validation. The goal of www.intedashboard.com version two was to identify and beta test functional requirements across multiple institutions. Between 2015 and 2017, the author met with over 150 TBL practitioners from 30 institutions for feedback through software demonstrations which was used to continuously improve www.intedashboard.com version 2. During this time, 20 institutions agreed to test version 2 in their classes. A survey completed by initial beta testers indicated that 75% of faculty would recommend the TBL platform and reported their students enjoyed using it. Real-time data was the most common benefit reported by over 80% of respondents while administrative time savings was cited by 50% of respondents (O'Dwyer, 2017). A study from Deakin University by Currey et al. (2019) reported "High satisfaction and student engagement with InteDashboard" and that 88% of faculty and 58% of students preferred digital all-in-one TBL with www.intedashboard.com to paper-based TBL (including responses of "no preference" these figures increase to 100% for faculty and 79% for students) as displayed in Fig. 6.

Level of Need Validation. To assess the level of the need for www.intedashboard.com, the author observed how many of the 20 institutions in the free beta test would convert to paying customers. By the end of 2017, 11 (55%) had converted to paying customers. At this point, the author deemed the beta test successful because the product was validated with workload and real-time data benefits and the need was validated with paying customers.

Financial Sustainability Validation. The third commercialization hurdle was to assess whether the platform could be financially self-sustaining. After the beta test, the technical team was increased to eight people and development began on a

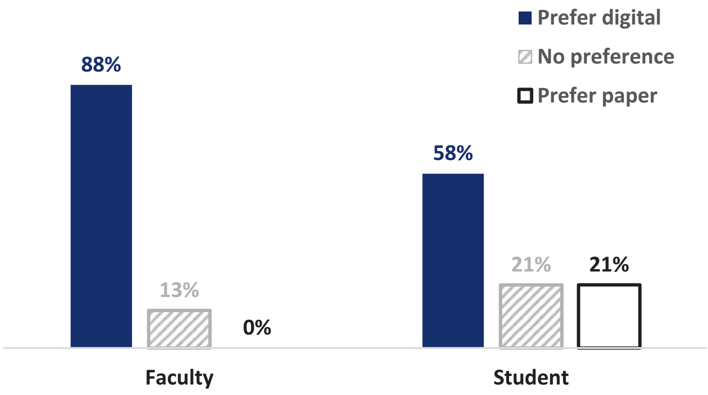

Fig. 6 Student and facilitator preferred TBL methods. (Source: adapted from Currey et al., 2019)

third-generation version of the platform. The third-generation version of www.intedashboard.com was released in 2019 and has a 96% faculty satisfaction rating. Today, over 100 institutions and thousands of educators and students around the world have used www.intedashboard.com for TBL. The platform is ISO 27001 certified for Information Security Management is used in 15 countries with servers in Asia-Pacific, Canada, the European Union, the United Kingdom, and the United States in compliance with data protection laws. After 5 years of operation as a separate, self-sustaining private sector entity with a full-time team of 13, the commercialization process has arguably been completed.

Facilitating Team-Based Learning with Real-Time Online Technologies

This section will describe the functionalities of www.intedashboard.com for implementing TBL such as: activity authoring, student-facing delivery, and instructor orchestration and assessment.

Activity Authoring

Activity authoring is one of the first parts of education technology encountered by teachers who prefer this process to be as easy and quick as possible. To achieve these objectives, three principals were utilized:

1. **Similar process:** Follow a similar look, feel, nomenclature, and process with existing technologies such as an LMS that some teachers are already familiar with.

2. **Rapid import:** Allow teachers to rapidly import activity questions and cases, class rosters, and team assignments.
3. **Step-by-step process:** Divide the activity authoring process into several steps and have the penultimate step consist of a preview or review process so that teachers can verify the setup.

Student-Facing Delivery

For students, the focus of the TBL platform is on the assessment of individual and team performance. Typically, other means will be used for communication such as speaking for an in-person class or a web conference tool in an online class. In addition to submitting assessments, some features valued by students are identified in Table 4.

Instructor Orchestration and Assessment Tools

Once an activity has begun, TBL educators need to monitor progress and facilitate.

Progress Monitoring

To monitor ongoing activities, teachers use real-time dashboards as described in Table 5.

Table 4 Student-facing delivery TBL technology considerations

TBL component	Student-facing considerations
IRAT	• Highly visibly countdown timer • Question response status
TRAT	• Ability to select and change team reporter • Immediate feedback
Applications	• Respond to cases that require a decision either as a single multiple-choice or more than one correct answer • Respond to cases with text, images, or files • Option to provide a rationale for the response

Note: Refer to section "Supporting Digital Teams Using Active Pedagogical Strategies" for information on the peer evaluation component

Clarifications and Facilitated Discussion

Instructors typically clarify misconceptions after the TRAT and facilitate a discussion after the applications. TBL technology features to support these processes are described in Table 6.

Personalizing Team-Based Learning Through Analytics

This section will describe how to use the data generated by www.intedashboard.com to personalize TBL through analytics.

Assessment Mechanics

In the DMTL workshop, assessment mechanics focuses on analysis techniques for collecting, organizing, and analyzing student data. This section will describe how data generated by TBL technology can be used for addressing trouble spots, adaptation, prediction, and continuous improvement.

More Time for Trouble Spots

TBL can save time by requiring students to complete prework before class. Students can review prework at their own pace allowing them to personalize content delivery. Class can then be used for IRAT, TRAT, and applications. As depicted in Fig. 7, data from the author's teaching showed average IRAT scores of 76% and TRAT scores of 93%. This allowed the author to prioritize teaching on the most difficult concepts. The easier concepts that students can understand individually or with the help of peers can be skipped which allows more time for difficult topics. In addition, with

Table 5 Progress monitoring elements

Type	Description
Timing	• Highly visibly countdown timer • Ability to adjust timing
Class level	• Class level view of students that have started, finished or are still working • Mean, median, high, and low statistics
Item level	• IRAT, TRAT, and application data correct percentage, distribution of responses, time on each question, and psychometric analysis
Student/team level	• Details of each student and team response by question
Team leaderboard	• Display of progress by team

Table 6 Instructor facilitation elements

TBL component	Description
Readiness assurance (after TRAT)	• Reveal the clarification requests made by different teams and the responses made by different teams to each question • View team member names by clicking on a team number
Application exercises	• Simultaneously reveal team responses which can be used to call on different teams to defend their choices • View the rationale that teams typed to support their choice • Electronic gallery walk technique: – Select several team responses for gallery walk voting – Students reconvene in their teams and view the selected response and vote for the best team response other than their own – Instructors can release the results of the gallery walk vote

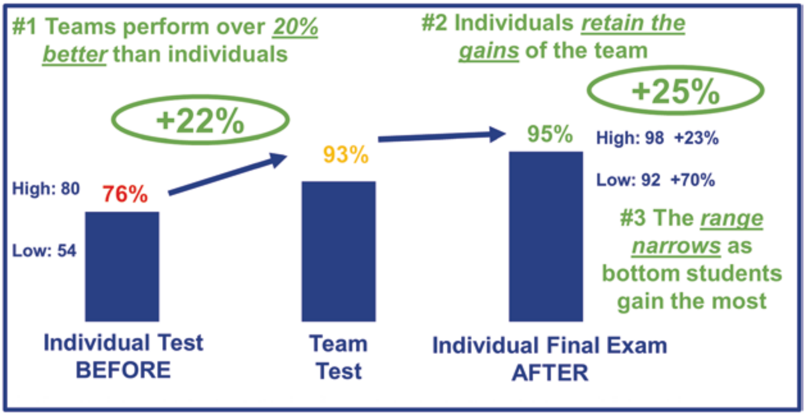

Fig. 7 Comparison of individual, team, and final exam scores. (Source: O'Dwyer & Wertz, 2018)

the real-time data dashboards, instructors know what the trouble spots are at the individual and team levels while students are still working which provides additional time to prepare to discuss these items. The author observed that lower scoring students tend to gain the most from this process because they benefit from a personalized discussion in their teams. Figure 7 shows the score range narrowing from 54% to 80% on the IRAT to 92% to 98% on the final exam. Higher scoring student performance has also increased which the author believes is because they benefit from providing explanations to lower scoring students during team discussions.

Adaptive Readiness Assurance Testing

Formative assessment data is plentiful because of the IRAT and TRAT process in each TBL session. IRAT and TRAT results can be used to identify difficult items in each TBL session. Difficult items can easily be repeated in subsequent TBL sessions until performance improves. Wertz and the author provided an example of how faculty can easily create an adaptive process where students are forced to recall difficult items individually and discuss them with peers and as a class each week until the difficult topic is mastered (O'Dwyer & Wertz, 2018).

Prediction

Some classes will have a TBL session weekly over a 15-week term. Wertz and the author (2018) used this data to show how it could be predictive of final semester grades after 3 weeks of class with a P-value of 2.2×10^{-16} and an adjusted R^2 value of: 0.3891. This could be used to predict which students may struggle early in a term so that interventions can be implemented that may mitigate adverse academic outcomes.

Continuous Improvement

TBL data can also be used for continuous improvement whereby educators review existing data from a past batch of students to improve the quality of questions and application exercises for future batches of students. Having all the TBL data in one platform has helped educators quickly access past data in seconds such as item analysis and team clarifications so that future assessments can be improved. This can also help faculty prepare for facilitation by reviewing trouble spots from previous classes.

Feedback Mechanisms

Six feedback mechanisms available in www.intedashboard.com are illustrated in Fig. 8 and described below except for peer evaluation which is described in section "Engagement and Accountability".

TRAT with Immediate Feedback After Each Attempt

The first occasion for feedback in the TBL process occurs during the TRAT. In the TRAT, teams agree on their first-choice answer for a given question and submit their response. Teams then get immediate feedback as to whether the response is correct or not. Teams keep submitting responses until they eventually get the correct answer. However, teams get less points with each attempt. For example, four points for the first attempt correct, two points for correct on the second attempt, one point for correct on the third attempt, and zero points for correct on the fourth attempt. Figure 9 provides an illustration of how this is done digitally. Absent digital TBL technology,

Fig. 8 TBL feedback mechanisms

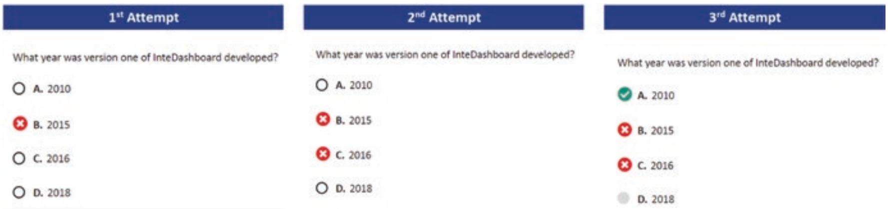

Fig. 9 Example of TRAT immediate feedback after each attempt

TBL educators have used paper-based alternatives because this process can be difficult to replicate in most general LMS.

Team Report and Clarification Requests After the TRAT

After the TRAT, teams receive a report with TRAT results. Teams then have the option to submit a clarification. This request is relayed to educators in real-time so they can prepare to respond. Refer to Fig. 10 for an example.

Facilitated Discussion After the TRAT

After teams submit clarification requests, educators can address them in a live facilitated discussion. The www.intedashboard.com facilitation screen displays clarification questions raised by teams which can be used by educators to respond directly or assign explanation responsibility to teams that did not request clarification. As an example, in Fig. 11, teams 1, 8, and 12 requested clarification regarding question 3. Team 9 (who do not request clarification) was assigned to provide an explanation.

Fig. 10 Team report and clarification request

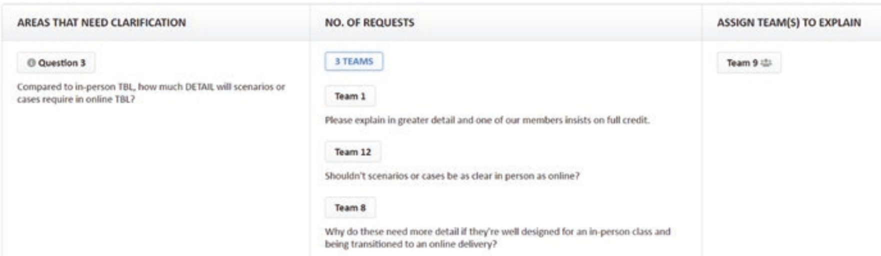

Fig. 11 Clarifications discussion

Simultaneous Reporting of Multiple-Choice Application Exercises

After teams make and submit their decisions for multiple choice applications, all team responses are reported simultaneously. With TBL 1.0, this can be done with paper voting cards with the letter of each voting choice. With an online TBL technology platform, this is done digitally and allows faculty to click on team numbers to identify team members and view any rationale that teams may have included for their decision. Finally, there is an option to reveal a correct answer after discussion which can provide closure for situations where there is a right and wrong answer. However, for situations that lack a definitive right and wrong answer, educators can elect not to reveal a correct answer. Figure 12 shows TBL 1.0 and TBL 4.0 methods.

Simultaneous Reporting and Gallery Walk of Free Response Application Exercises

Free response application exercises require teams to create or critique a work artifact such as writing a treatment plan with free text or by uploading a file or image. In these situations, educators can simultaneously report digitally in a similar manner as described above. Teachers can view work artifacts, team member names and supporting comments by clicking on team numbers. For text responses, faculty can also specify a minimum or maximum number of words and have the option to highlight correct answer keywords.

Fig. 12 TBL 1.0 and TBL 4.0 simultaneous reporting

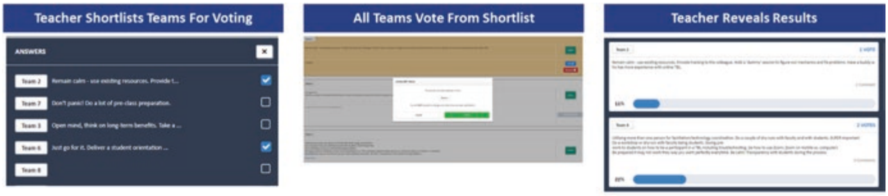

Fig. 13 Electronic gallery walk

There is also an option for an electronic gallery walk. In this facilitation technique educators may shortlist team responses for voting. Students will then reconvene in their teams to vote for the best response on the shortlist and provide a comment justifying their vote. Teams cannot vote for themselves. Educators then reconvene a plenary session and display the vote totals and justifications. This can be used to support further discussion. All the response data is tracked and downloadable which can be used to create future multiple-choice questions since very plausible wrong answers can be identified easily by the vote totals (Fig. 13).

Supporting Digital Teams Using Active Pedagogical Strategies

This section will describe how an all-in-one TBL technology platform can support team management, engagement, accountability, and faculty development.

Pedagogical Methods for Team Management

Key www.intedashboard.com functionalities to support team management are described below.

Sections and Teams

The most basic functionality is the ability to assign students to teams easily and quickly as well as allocate team grades to members of each team. In addition, there is the ability to divide a course into subsections. TBL educators, particularly in online classes, may divide a large class of 90 students and 15 teams into 3 smaller sections of 30 students and 5 teams to make facilitated discussions easier and more engaging.

Team Reporter

Team reporter functionality was developed for use during team activities such as the TRAT and the applications. This feature permits only one person to respond on behalf of the team to avoid the confusion of having two different people answer differently on behalf of the team. Teams may change team reporter which allows teams to rotate this role. Some educators have found this useful as the team reporter can sometimes take on a facilitator role during team discussions.

Limited Display of Individual Responses to Encourage Discussion

During the TRAT, a conscious decision was made not to display all the responses of individual team members. TBL educators were concerned that if students could see how all team members responded individually on one screen, they would be inclined to replace discussion with majority rules voting. Instead, team members are required to verbally discuss their answers which some TBL educators feel provides for better interactions.

Immediate Feedback After Each TRAT Team Response

After each response on the TRAT, teams receive immediate feedback as to whether their answer is correct. Sibley has described the benefits for team dynamics of this component of the TBL process as follows:

> The pushy student with the wrong answer may be a few scratches away from having the team stop listening. Similarly, a quiet student can be drawn into the conversation if the team recognizes that they often have the right answers and that listening to the quiet student will help the team. Finally, the chronically underprepared student is usually found out by their teammates, and peer pressure and peer evaluation can sometimes motivate these underprepared students to work harder. (Sibley, J. (n.d.-a), Team Readiness Assurance Outcomes)

Engagement and Accountability

Functionalities for peer evaluation, individual and team assessment linkages, and confidence-based assessments can support engagement and accountability.

Peer Evaluation

Peer evaluation is a TBL process where team members provide feedback to other members of their team. The feedback is generally shared with team members on an anonymous basis. This can help students become accountable to their teammates for their preparation and contribution to team activities. Peer evaluation techniques vary more than other components of the TBL process which has required great configuration flexibility for a TBL software platform. There are three peer evaluation techniques that can be configured in www.intedashboard.com which are described in Table 7.

Peer evaluations approaches can also vary in terms of who or what is evaluated. As a result of requests from TBL educators, www.intedashboard.com can support three units of evaluation:

- Evaluate teammates
- Evaluate yourself
- Evaluate your team as a collective unit

Peer evaluation also varies in frequency. For example, Clark et al. (2018) recommend more frequent peer evaluations for greater accountability in online TBL classes. A common cycle for an in-person class might include:

- Orientation peer evaluation during first few weeks of class.
- Formative ungraded peer evaluation midway through the term.
- Summative graded peer evaluation at the end of the term.

Table 7 Peer evaluation techniques

Technique	Description
Michaelsen method or "divide up the money"	• Students are given points to divide among teammates such as 50 points to allocate among 5 teammates • Students cannot give the same number of points to all teammates
Quantitative	• Students provide a rating on a scale which runs from 2 points to 11 points • Educators have the option to provide a rubric for each rating
Qualitative	• Students provide text comments in response to a prompt such as "what does your teammate do well?" • Educators can specify a minimum or maximum number of words

Individual and Team Assessment Linkages

The TBL process includes individual assessments which are completed prior to an identical team assessment. This mechanism for individual accountability can help provide an incentive for students to come to class prepared to contribute to their team which can support positive team dynamics. In addition, some institutions have also utilized functionality for an individual version of the team application exercise (either before or after the team version) to enhance individual accountability.

Confidence-Based Individual Readiness Assessment Tests

Some TBL educators conduct confidence-based IRATs where students must respond by allocating points depending on their confidence level. As an example, if a student is fully confident on choice A (out of four options), they would put all four points on A. If they are guessing between A and B, they would be two points on A and two points on B. If a student is guessing, they might put one point on each answer choice. Refer to Fig. 14 for an example.

Some TBL educators have indicated to the author that this helps them distinguish between students achieving a correct answer by guessing instead of knowing the correct answer. Other TBL educators have told the author that they have observed a metacognition effect of this approach which helps students reflect and assess their preparation levels and come to class more prepared in the future which can improve their team contributions.

Faculty Development

An all-in-one TBL technology platform can both support and benefit from faculty development. The faculty development described in this section relates to training faculty in the TBL methodology rather than product training about how to use a specific TBL technology.

Enabling Faculty Development

In 2018, www.intedashboard.com was first used for TBL faculty development in live 2-h live online workshops delivered with the TBL methodology. These workshops expanded access to TBL faculty development. Now, the www.intedashboard.com TBL platform has been used in over 60 online TBL professional development workshops with over 1500 participants from 30 countries. Results have been positive and research publications are pending.

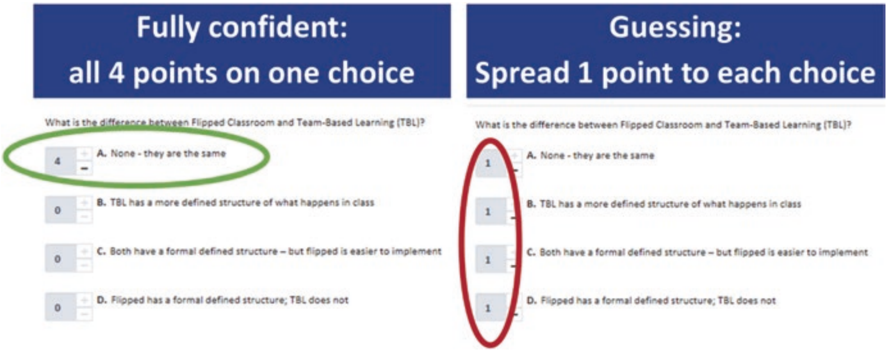

Fig. 14 Confidence-based testing example

Faculty Development as Beta Test

Throughout the ongoing development of www.intedashboard.com, the software engineers responsible for coding also participated in some of the aforementioned faculty development workshops. This experience allowed technical staff to observe user behavior firsthand which they believe aided with the software development process.

Conclusion

This chapter has been limited to work that is largely descriptive or based on relatively small sample sizes. As with any technology, some aspects of this chapter may be out of date by the time of publication. Academic integrity can be an important issue, but it was beyond the scope of this chapter. Finally, not all barriers to TBL implementation such as content creation will be fully mitigated by a TBL 4.0 all-in-one TBL technology platform. In the future, there could be opportunities for more evaluative and comprehensive work which makes use of the rapidly expanding TBL data set. TBL technology could be enhanced to provide sharing of resources such as question and case materials between different institutions or artificial intelligence-based grading of free responses both of which could materially reduce faculty workload.

This chapter began with the TBL process and modalities and used four versions of TBL technology adoption to describe the need for TBL technology to reduce faculty workload, deliver TBL in online classes, and provide educators real-time data with an all-in-one TBL technology platform. The creation, incubation, and commercialization of the www.intedashboard.com TBL technology platform were described. Section "Facilitating Team-Based Learning with Real-Time Online Technologies" described key elements of TBL technology for instructor activity authoring, student-facing interface, and real-time monitoring and facilitation.

Section "Personalizing Team-Based Learning Through Analytics" highlighted opportunities to utilize the data generated through a TBL technology platform to personalize TBL through analytics and enable rapid feedback mechanisms. Section "Supporting Digital Teams Using Active Pedagogical Strategies" described how this TBL technology platform can support team management, engagement, accountability, and faculty development.

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Digitally Mediated Tools for Facilitating High-Quality Team-Based Programming Projects

Zhewei Hu and Edward F. Gehringer

Abstract In today's digital society, many digitally mediated tools are designed, developed, and used to teach students how to program. One example is the educational programming tool Scratch, developed at MIT. However, most educational tools are designed for K-12 and CS0 to CS2 students. Relatively few are developed for advanced undergraduate or graduate students. This chapter introduces several digitally mediated tools that can be used by more advanced students in industry-like programming projects. The first tool is test skeletons, which are test methods without the test bodies. The second one is an IDE (Integrated Development Environment) plugin to record student programming steps. Then, we introduce three Internet bots, which are either open source or free to use. These bots can not only detect system-specific guideline violations but also aggregate that information (including code smells (https://en.wikipedia.org/wiki/Code_smell) and the results of test execution) on a single GitHub (https://en.wikipedia.org/wiki/GitHub) pull-request (https://en.wikipedia.org/wiki/Distributed_version_control#Pull_requests) page. These tools aim to facilitate programming and code reviewing and help student teams to write high-quality code.

Introduction

Software engineering courses typically require students to work on programming projects and submit code for grading. It is increasingly common for programming projects to specify GitHub pull-requests as deliverables. Also, it is essential for students to receive timely support and feedback on their code throughout the projects. However, it is difficult for teaching staff to provide instant support and feedback for student-submitted code, especially in large classes. Each semester 50–120 students

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enroll in our software engineering course. There are typically four or five staff members, including the instructor and several teaching assistants. Each student team of 2–4 members works on a different programming project; hence, each staff member needs to mentor five or more student teams for each assignment. Based on our previous experience, we recognize the importance of providing timely support and feedback for student programming projects. Therefore, we have designed and developed several digitally mediated tools to promote the programming and code-reviewing process.

All these digitally mediated tools can be adopted for individual and collaborative activities. We focus on utilizing these tools in collaborative activities. In our case, we required students to form teams to collectively work with these tools in programming projects. This has several advantages: (1) team members can use pair programming,[1] which helps them learn an unfamiliar platform more quickly, and results in higher quality code (Williams et al., 2000); (2) working in teams cultivates the students' collaboration and communication skills; and (3) collaborative activities are closer to industrial practice, which is beneficial for the career development of students.

Digitally Mediated Tools for Facilitating Programming

In this section, we discuss how to use an innovative test-driven approach together with two digitally mediated tools to facilitate high-quality team-based programming projects.

In 1957, D.D. McCracken introduced the concept of Test-Driven Development (TDD) in his book *Digital Computer Programming* (McCracken, 1957). Long afterwards, in 2003, Kent Beck "rediscovered" the test-driven approach and reintroduced the TDD mantra—"red/green/refactor" (Beck, 2003): developers first write failing tests to describe the functionality of the code they are about to develop (red); then they implement the code to make tests pass (green); and finally, they refactor the code (refactor). This iterative process gives developers confidence in the soundness of the current functionality and ensures that the newly written code does not change the behavior of previous features.

The test-driven approach proved attractive to educators, many of whom conducted experiments evaluating the effectiveness of the test-driven approach in computer science courses. However, experimental results are inconsistent; some studies demonstrate that the test-driven approach can help students write better code and improve their design skills (George and Williams, 2004; Desai et al., 2009), while others have shown that it does not help produce high-quality code, especially when used by inexperienced developers like students (Siniaalto and Abrahamsson, 2007; Pančur and Ciglarič, 2011).

[1] https://en.wikipedia.org/wiki/Pair_programming

We believe the test-driven approach is a powerful tool for producing high-quality code. To introduce it to students, we have developed a tool called *test skeleton* and adopted an IDE plugin named *Activity Tracker*[2] to not only familiarize students with the test-driven approach but also induce them to adhere to the test-driven process.

Previous studies have shown that it is not easy to adhere to the test-driven process all the time. Beller conducted a large study with more than 400 software engineers in 5 months. The results showed that only ten engineers strictly used the test-driven approach all the time (Beller et al., 2015). Kou recorded the development process of a research tool named *Zorro* (Kou and Johnson, 2006) in 8 weeks. Although the authors used the test-driven approach during the development, the results disclosed that they were able to comply with the test-driven approach only 23% of the time (Kou et al., 2010). Both authors mentioned that some code modifications are either not suitable or not straightforward for the test-driven approach, such as configuration file changes, or web interface testing. So, they applied test-driven techniques pragmatically instead of strictly adhering to them all the time. Since our experiments were done with a web application, and our team-based programming projects lasted more than 1 month, we deemed that students had pragmatically applied the test-driven techniques if they had spent at least 20% of their time adhering to the test-driven process.

Expertiza

Our programming projects are based on an education-oriented Open-Source Software[3] (OSS) project named *Expertiza* (Gehringer et al., 2007). It is an online peer assessment system whose development was funded by the National Science Foundation. Since 2007, Expertiza has become the main source of programming projects for our software engineering masters course, Object-Oriented Design and Development. Expertiza has been used at 22 institutions around the world and served over 9000 students. More than 370 people (most of them students) have contributed to Expertiza's Ruby on Rails[4] codebase hosted on GitHub and helped the system undergo several major upgrades. Moreover, Expertiza uses RSpec[5] as the testing framework, which supports test-driven development and is extensively used in industry.

[2] https://plugins.jetbrains.com/plugin/8126-activity-tracker

[3] https://en.wikipedia.org/wiki/Open-source_software

[4] https://en.wikipedia.org/wiki/Ruby_on_Rails

[5] https://en.wikipedia.org/wiki/RSpec

```
def super_admin?
    role.name == 'Super-Administrator'
end
```

(a)

```
describe '#super_admin?' do
    it 'returns true if the role name of the current user is Super-Administrator'

    it 'returns false if the role name of the current user is not Super-Administrator'
end
```

(b)

```
describe '#super_admin?' do
    it 'returns true if the role name of the current user is Super-Administrator' do
        allow(user).to receive(:role).and_return(double(:role, name: 'Super-Administrator'))
        expect(user.super_admin?).to be true
    end

    it 'returns false if the role name of the current user is not Super-Administrator' do
        allow(user).to receive(:role).and_return(double(:role, name: 'Student'))
        expect(user.super_admin?).to be false
    end
end
```

(c)

Code 1 An example of the method that needs to be tested (**a**), corresponding test skeletons (**b**), and completed tests (**c**)

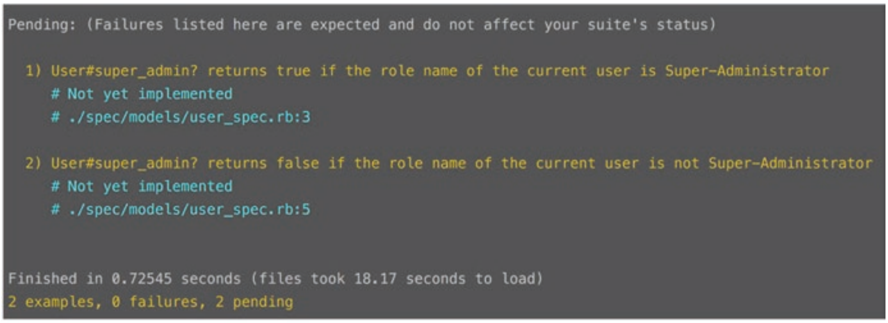
Test Skeletons

The test skeleton is the first digitally mediated tool we want to introduce. Each test skeleton is a test method that contains a specification (signature) but not a test body (Hu et al., 2019). Test skeletons are elaborated guidelines, which can show students which kinds of tests are required and discourage them from writing "shallow tests" (Hu et al., 2018)—tests that concentrate on irrelevant, unlike to fail situations or system functions.

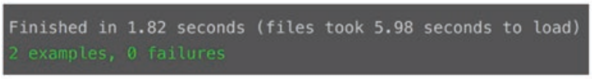
For example, assume we want to ask students to test the *super_admin?* method shown in Code 1a. We provide students with a test skeleton which includes two scenarios with self-explanatory testing messages shown in Code 1b. It is worth mentioning that test skeletons are executable. If students execute a list of test skeletons, the output is a list of pending requirements that have not been implemented displayed in Fig. 1a. After students successfully fill out the test skeletons with code presented in red in Code 1c, the execution results will be similar to Fig. 1b.

In real programming projects, tests can be much more complicated than the example above. Also, test skeletons do not provide an exhaustive list of tests, which means that students are always responsible for writing tests for newly created methods using the test-driven approach. Although the above example is written in Ruby[6] with RSpec testing framework, the test skeleton can be adopted for any programming language and any testing framework.

[6] https://en.wikipedia.org/wiki/Ruby_(programming_language)



(a)



(b)

Fig. 1 The execution output of test skeletons (**a**) and completed tests (**b**)

IDE Plugin

We used an IDE plugin named Activity Tracker to record the programming steps for each student. With this data, we can examine whether students adhere to the test-driven technique pragmatically. For each program step, the Activity Tracker records five attributes, namely (1) timestamp, (2) current user, (3) keyboard events (character addition or deletion), (4) files in focus (where the cursor is currently), and (5) cursor location (line number together with column number). Based on source code and Activity Tracker records, we can reproduce the student programming processes.

To examine student compliance with the test-driven process, we aggregated adjacent similar programming steps into *periods*. For example, Table 1 shows an example of ten student programming steps. We can aggregate them into three periods. The first period is from steps 1 to 3, the second period is from steps 4 to 7, and the last period is from steps 8 to 10. According to files in focus, steps 1–7 edited the test (spec) file, and steps 8–10 edited the source code.

Hence, it is straightforward to group steps 8–10 into one period. For steps 1–7, the cursor location moved a long distance between steps 3 and 4. After cross-checking with the test code, we noticed that the student worked on two different test methods in steps 1–3 and steps 4–7. So, we considered them to be two periods. This is because only when students create one or more tests first and then modify the corresponding method in source code, we consider them to comply with the test-driven technique. If students edit different source-code methods or test methods in the meanwhile, we consider them as different periods.

Table 1 An example of student program steps

Step	Timestamp	Current user	Keyboard events	Files in focus	Cursor location
1	10:38:09.04	Student	KeyEvent	./spec/models/user_spec.rb	67, 6[a]
	3	1	(addition)		
2	10:45:26.76	Student	KeyEvent	./spec/models/user_spec.rb	74, 40
	2	1	(addition)		
3	10:45:26.98	Student	KeyEvent	./spec/models/user_spec.rb	74, 46
	6	1	(deletion)		
4	10:53:33.72	Student	KeyEvent	./spec/models/user_spec.rb	6, 40
	2	1	(addition)		
5	10:53:33.81	Student	KeyEvent	./spec/models/user_spec.rb	6, 42
	2	1	(addition)		
6	11:20:28.87 2	Student 1	KeyEvent (addition)	./spec/models/user_spec.rb	8, 5
7	11:20:38.82	Student	KeyEvent	./spec/models/user_spec.rb	10, 4
	2	1	(deletion)		
8	11:20:44.91	Student	KeyEvent	./app/models/user.rb	70, 4
	6	1	(deletion)		
9	11:20:45.07	Student	KeyEvent	./app/models/user.rb	71, 12
	3	1	(addition)		
10	11:22:36.32	Student	KeyEvent	./app/models/user.rb	69, 14
	8	1	(addition)		

[a]67, 6 means the cursor was located line 67 and column 6

The editing sequence is one very important factor for checking student compliance with the test-driven process. We are inspired by the heuristics proposed by Kou et al. (2010) and Fucci et al. (2016) and define six categories for different kinds of periods or period combinations, namely, *test modification*, *test configuration*, *code refactoring*, *code configuration*, *TDD*, and *test-last*, as shown in Table 2. Among them, the first four categories are atomic. If student programming steps are suitable for only one of these atomic categories, we classify them into one of these four categories. Otherwise, we try to classify them into either TDD or test-last categories. The biggest difference between TDD and test-last categories is the sequence of writing tests and refactoring source code. For the TDD category, although the whole process can include multiple iterations, each iteration should start with writing tests. For the test-last category, the entire process can also include multiple iterations, and each iteration should start with refactoring source code. In addition, it is OK for test configuration and code configuration to happen several times during the entire process.

Table 2 Definitions and patterns of period categories

Period category	Definition/pattern
Test modification	Modify the test code
Test configuration	Setting test configuration and/or data
Code refactoring	Refactoring the source code
Code configuration	Setting source code configuration
TDD	…→[Test modification → Code refactoring]$_n$ → …
Test-last	…→[Code refactoring → Test modification]$_n$ → …

Experimental Design and Results

We conducted two quasi-experimental control studies in our course. Thirty-five masters students participated in the first study. Students were required to form teams of two to three members to work on programming projects: refactoring the existing code base and writing unit tests[7] or integration tests.[8] We chose 12 projects for this study. Among them, six projects were assigned to the TDD group, and students were required to be done using a test-driven approach; the other six projects were allocated to the non-TDD group, and students were asked to use the traditional test-last approach. There are several reasons why we chose these refactoring projects. First, the existing test coverage of these source code was very low and some of them did not have corresponding tests at all. Hence, students had enough opportunities to write tests. Second, compared with adding new features, refactoring the existing codebase made it easier for us to reduce the workload of the projects and distribute the workload evenly among different projects.This was because many students had never written code before while complying with the test-driven process. Reducing the project size could familiarize the TDD group students with the test-driven process and set aside time for team members to allocate work. Besides, with similar workloads for the TDD and non-TDD groups, the comparison results became more persuasive.

We provided the test skeletons and the IDE plugin for student teams in both groups. We asked each student team to allocate work for each team member. As a result, each team member could focus on refactoring a portion of the codebase and writing corresponding tests with a subset of test skeletons while complying with the correct programming steps. The IDE plugin was responsible for recording the programming steps for each student.

We conducted an anonymous survey to document the usefulness of test skeletons, the extent to which students followed the test-driven approach, and the concerns, suggestions, and ideas about using the test-driven approach in programming projects. Results showed that almost 70% of students had positive attitudes toward

[7] https://en.wikipedia.org/wiki/Unit_testing

[8] https://en.wikipedia.org/wiki/Integration_testing

test skeletons and thought that they were useful. Further, more than half of students in the TDD group claimed they followed the test-driven approach strictly.

We collected the programming steps from ten students who voluntarily shared this information with us. Nine students were in the TDD group and the last one (student 18) was in the non-TDD group. We analyzed three aspects of the experimental results: (1) compliance with the test-driven process, (2) quality of source-code changes, and (3) test quality. To analyze student compliance with the test-driven process, we aggregated their programming steps into periods and classified the periods into six categories as defined in Table 2. We also visualize the programming steps of 10 students (shown in Fig. 2). Each bar represents the programming steps of one student. The length of the bar indicates the programming duration in minutes. In each bar, different colors represent six categories of the abovementioned periods. We found that students in the TDD group spent on average 31% of time complying with the test-driven approach, while students in the non-TDD group spent on average 6% of time adhering to the test-driven approach. Therefore, we concluded that students in the TDD group applied the test-driven approach pragmatically during the programming projects, while those in the non-TDD group did not follow the test-driven process.

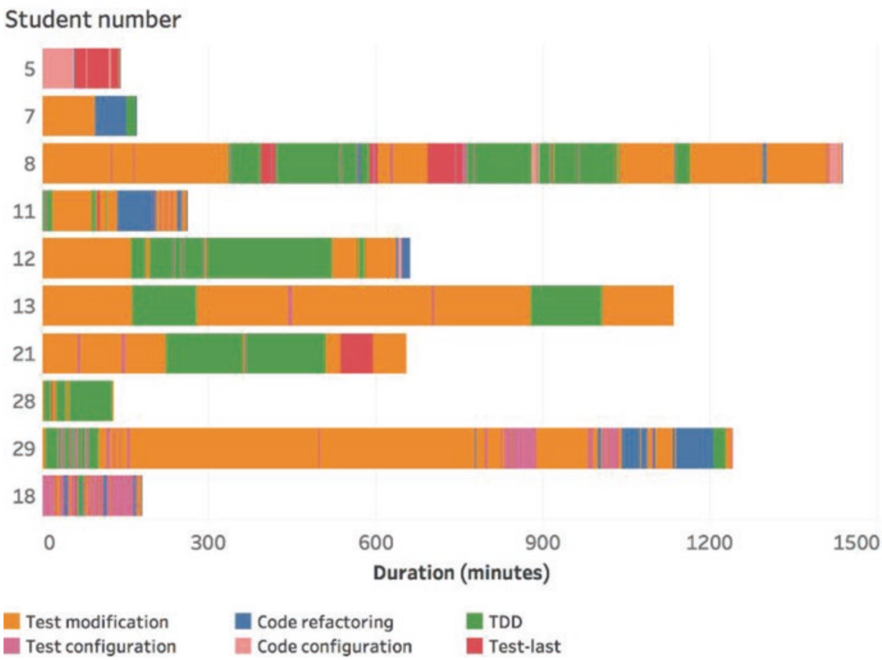


Fig. 2 Bar chart classifying student programming steps (Hu et al., 2019)

We analyzed the test coverage and test quality between the TDD group and the non-TDD group. Specifically, we measured the statement coverage[9] and Mutation Score Indicator (MSI).[10] Results showed that the tests written by the TDD group had significantly higher statement coverage than those written by the non-TDD group. But there was no significant difference in test quality between the two groups. Moreover, we tallied 13 mistakes that occur frequently in student code (Hu et al., 2018), without finding a significant difference in the code refactoring quality between two groups.

Forty-eight students participated in the second study. Students were asked to form teams of three to four members and add new features to Expertiza along with writing high-level feature tests.[11] We prepared six programming projects for student teams. Each project was to be chosen by two teams. The teams in the TDD group were required to use the test-driven approach, and those in the non-TDD group were asked to use the traditional test-last approach. In addition, we also prepared test skeletons and the IDE plugin for all students who participated in the second study.

We also conducted an anonymous survey similar to the one from the first study. We found that only around 20% of students in the TDD group considered that they followed the test-driven approach strictly, and more than half of students thought that feature tests in programming projects from the second study were harder than unit tests or integration tests in the projects from the first study. After looking into the comments, we deduced several reasons why students did not comply with the test-driven approach in the second study: (1) it was difficult for them to learn enough about Expertiza in such a short time; (2) there was a learning curve on figuring out how to write high-level feature tests; and (3) it was challenging to write feature tests to present the desired functionality before implementing the real feature.

Code 2a shows a simplified example of the test skeletons for feature tests. The test skeletons are more like elaborated project requirements with different use cases. Code 2b displays the completed feature tests, which mock high-level user behaviors. In contrast to unit tests or integration tests, which only made students focus on one or a few methods, feature tests required students to understand the operation of high-level features, which typically involve multiple files. Although it might seem that feature tests do not need to deal with individual methods, writing robust tests before implementing the feature requires students not only to be familiar with the syntax of the testing framework but also to have the ability to specify the desired functionality first and then to convert it to test specifications. Overall, we think it is not suitable for students to work on new features of a system and write high-level feature tests while adhering to the test-driven approach.

[9] https://en.wikipedia.org/wiki/Code_coverage#Basic_coverage_criteria

[10] MSI is used to measure test thoroughness and fault-finding capability of tests. See https://en.wikipedia.org/wiki/Mutation_testing

[11] Also known as functional test, see https://en.wikipedia.org/wiki/Functional_testing

```
describe 'Accept/reject new user requests' do
  context 'on users#list_pending_requested page' do
    context 'when super-admin or admin rejects a requester' do
      it "displays 'Rejected' as status"
    end

    context 'when super-admin or admin accepts a requester' do
      it "displays 'Accept' as status and sends an email to the new user"

      context 'using name as username and password in the email' do
        it 'allows the new user to login Expertiza'
      end
    end
  end
end
```

(a)

```
describe 'Accept/reject new user requests' do
  context 'on users#list_pending_requested page' do
    context 'when super-admin or admin rejects a requester' do
      it "displays 'Rejected' as status" do
        visit '/'
        login_as 'super_administrator2'

        visit '/users/list_pending_requested'
        choose(name: 'status', option: 'Rejected')
        click_on('Submit')

        expect(requested_user.status).to eq('Rejected')
      end
    end

    context 'when super-admin or admin accepts a requester' do
      it "displays 'Accept' as status and sends an email to the new user" do
        visit '/'
        login_as 'super_administrator2'

        visit '/users/list_pending_requested'
        choose(name: 'status', option: 'Approved')
        click_on('Submit')

        expect(request_user.status).to eq('Approved')
        expect(email.subject).to eq("Your Expertiza account and password have been created.")
        expect(email.sender).to eq("expertiza.development@gmail.com")
      end

      context 'using name as username and password in the email' do
        it 'allows the new user to login Expertiza' do
          visit '/'
          fill_in 'login_name', with: 'approved_requster1'
          fill_in 'login_password', with: 'password'
          click_button 'Sign in'

          expect(page).to have_content("Login successfully!")
        end
      end
    end
  end
end
```

(b)

Code 2 An example of the test skeletons for feature tests (**a**) and completed tests (**b**)

Digitally Mediated Tools for Facilitating Code Reviewing

It is crucial for students to receive timely feedback about the coding quality during their programming projects. However, it is difficult for teaching staff to provide instant feedback, especially in a large class. Researchers have explored various approaches to provide automated feedback on student programming projects, such as static code analysis, automated tests, Intelligent Tutoring Systems (ITS), and AI techniques.

Our software engineering masters course, Object-Oriented Design and Development, makes the OSS project Expertiza the code base of programming projects. The Expertiza codebase is hosted on GitHub and we integrated several digitally mediated tools to GitHub to improve the code quality of student programming projects. We are using Code Climate[12] as the static code analyzer,[13] Travis CI[14] as the continuous integration[15] service, and Coveralls[16] as the code coverage[17] plugin. Whenever students create or modify GitHub pull-requests, these tools will be triggered automatically, then analyze the student code and send feedback back to students within minutes.

Although these tools are free to use and can prompt student contributions to follow best coding practices, pass existing tests, and achieve decent test coverage, they cannot examine system-specific guideline violations and explicitly display all elaborated information from existing digitally mediated tools on one GitHub pull-request page. Based on the first author's code-review experience, we gave many suggestions related to system-specific guideline violations. This is because our programming projects require students to refactor the existing codebase and/or add new features that are compatible with the current ones, instead of creating a new application from scratch. Therefore, satisfying static code analysis, passing automated tests, and achieving high test coverage cannot guarantee that the code is good enough to merge into the codebase. As a result, we need to design and implement new tools to automatically detect the system-specific guideline violations and aggregate information from the existing tools on one GitHub pull-request page to further help students write high-quality code in their programming projects. To automate this process, we integrated three Internet bots into the Expertiza GitHub repository.

Danger Bot

The first Internet bot is called the Danger bot. This bot is based on a Ruby gem called *Danger*. We customized the Danger bot to mainly examine five aspects of a GitHub pull-request: (1) pull-request title, (2) the number of line additions and deletions, (3) student code commits, (4) modified files, and (5) Git *diff* information that includes the student code changes in detail. The Danger bot can detect more than 40

[12] https://codeclimate.com/

[13] A tool to conduct the static program analysis, see https://en.wikipedia.org/wiki/Static_program_analysis

[14] https://en.wikipedia.org/wiki/Travis_CI

[15] https://en.wikipedia.org/wiki/Continuous_integration

[16] https://coveralls.io/

[17] https://en.wikipedia.org/wiki/Code_coverage

Expertiza-specific guideline violations; examples include (1) retaining debug code in submitted code, (2) adding new features without writing corresponding automated tests, (3) submitting skipped or unimplemented tests, (4) changing the database schema[18] file while there are no database migrations,[19] and (5) modifying package management[20] files without approval. You can find the full list of guidelines in the Expertiza GitHub repository.[21]

Figure 3 illustrates one GitHub pull-request comment automatically created by the Danger bot after it analyzed the student-submitted code. The comment includes three sections. The first section is about a welcome message and some instructions for students. The second section contains the warning messages given by the Danger bot. The last section includes the error messages. Each message maps to one system-specific guideline violation detected by the Danger bot. If students resolved a certain violation, the corresponding text will be struck through with a green check in the front. It is worth noting that the message for resolved violations will not be removed. The Danger bot keeps all history for future reference. The difference between the warning and error messages is that the error messages reveal more severe violations and have a higher priority on being resolved. If students do not resolve violations associated with the error messages, the entire pull-request will be marked as failed, which will dramatically reduce the likelihood of merging their code.

Travis CI Bot

We implemented the Travis CI bot based on an OSS project named *TravisBuddy*.[22] As mentioned above, although we were already using Travis CI as the continuous integration service for the Expertiza GitHub repository, it is not straightforward for students to fetch the test execution results and figure out the error messages and stack trace[23] of failed tests. The Travis CI bot can overcome this by excerpting the information related to failed tests from the test execution log and presenting it on the GitHub pull-request page. Figure 4a displays one comment created by the Travis CI bot with failed test information folded. By clicking the black triangle, students can

[18] https://en.wikipedia.org/wiki/Database_schema

[19] Also known as schema migration, see https://en.wikipedia.org/wiki/Schema_migration

[20] Package management is done by package managers, see https://en.wikipedia.org/wiki/Package_manager

[21] https://github.com/expertiza/expertiza/blob/master/Dangerfile

[22] https://github.com/bluzi/travis-buddy

[23] https://en.wikipedia.org/wiki/Stack_trace

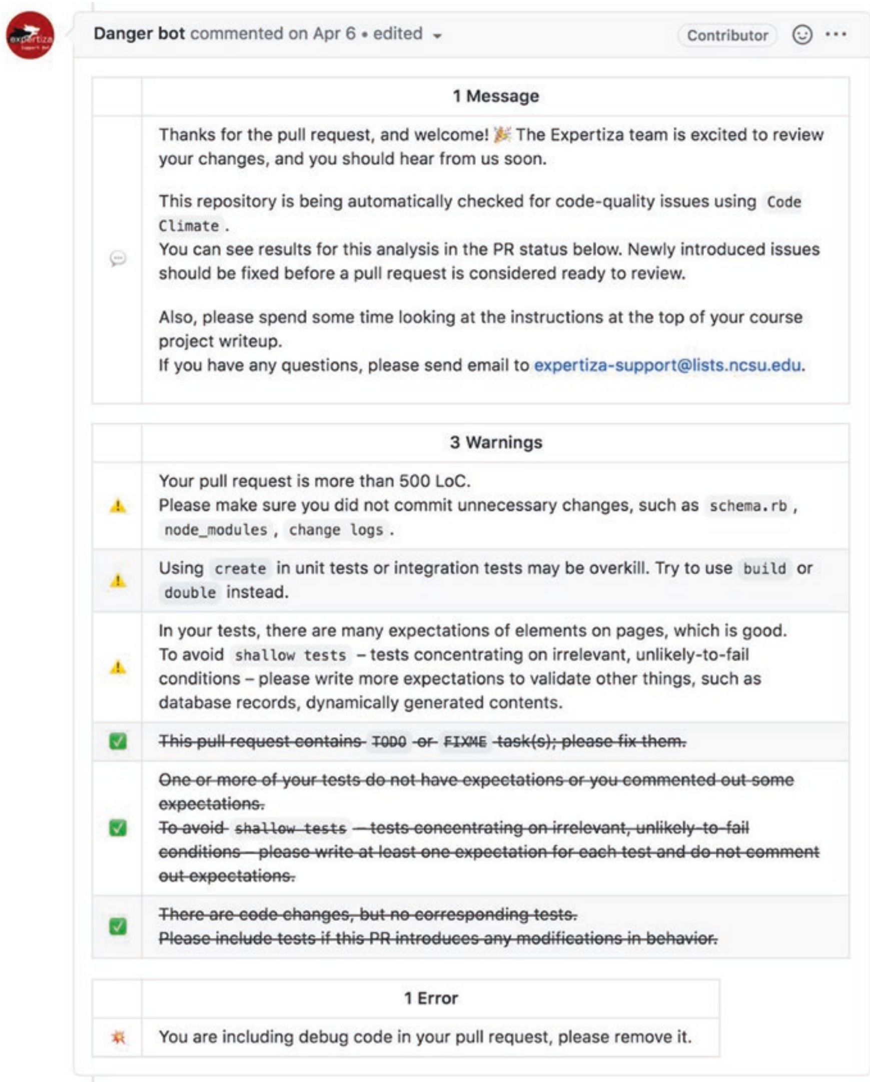
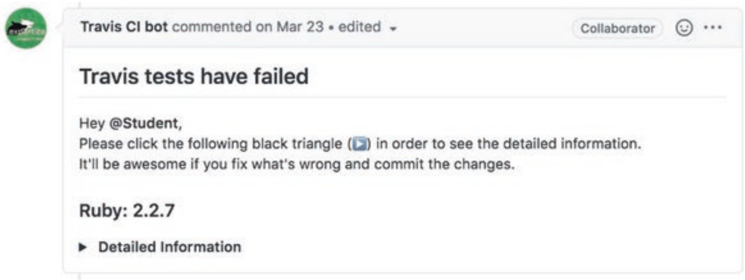
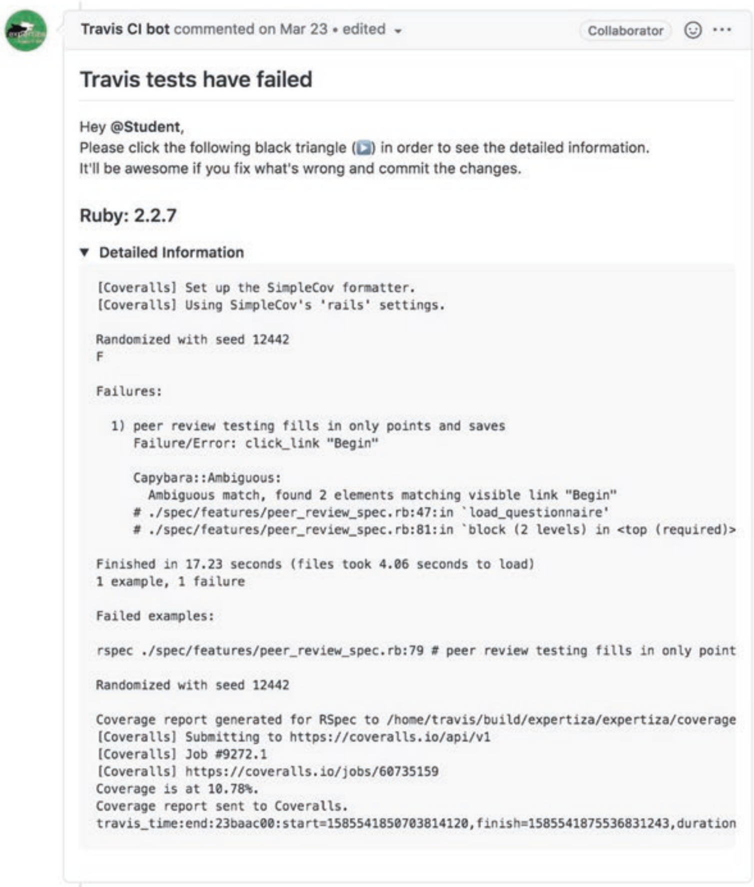


Fig. 3 A pull-request comment created by the Danger bot

check which tests failed and find the corresponding error messages and stack trace. Figure 4b presents the same comment made by the Travis CI bot with failed test information unfolded. If all tests pass, the Travis CI bot will congratulate students as shown in Fig. 5.



(a)



(b)

Fig. 4 A pull-request comment created by the Travis CI bot with the failed test information folded (**a**) and unfolded (**b**)

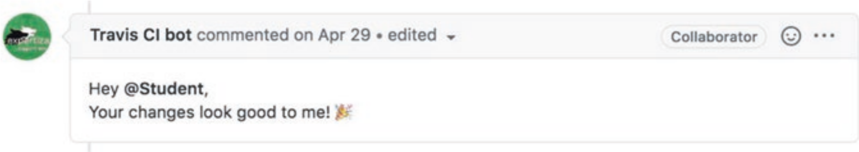


Fig. 5 A pull-request comment created by the Travis CI bot with all tests pass

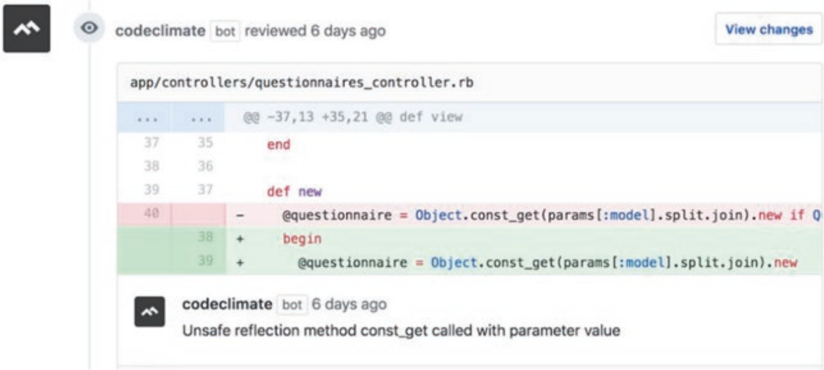


Fig. 6 An inline comment created by the Code Climate bot pinpointing an issue detected by the static code analyzer

Code Climate Bot

We implemented the Code Climate bot to enhance the functionality of Code Climate, the static code analyzer used for Expertiza. Although Code Climate can detect a variety of code smells, it displays the information on a separate web page and associates one code smell with a truncated code snippet. This is an inconvenient way for students to get an overview of code smells for one file. Students usually have to jump back and forth between the code climate web page and the source code to cross-check the information. The Code Climate bot can solve this problem by inserting inline comments directly in the source code and reminding students to fix problems, as shown in Fig. 6.

Internet Bot Behavior Adjustment

After testing the three Internet bots in our software engineering masters course, Object-Oriented Design and Development, we detected several problems with our bots; the Danger bot created multiple false-positive warnings and failed to detect several system-specific guideline violations; the Travis CI bot had an average response time of over 18 min before sending out excerpted test execution results;

and the Code Climate bot created a large number of inline comments, which increased the page load time and reduced the readability of the pull-request pages.

After noticing these issues, we analyzed the cause and adjusted the behaviors of these bots accordingly. For the Danger bot, we figured out that the false positives came from two aspects: (1) imprecise regular expression[24] and keyword matching and (2) the fact that we only considered code changes in modified files, and ignored added, renamed, and deleted files.Therefore, the Danger bot was not able to detect violations accurately.

For the Travis CI bot, the slow response time is because (1) there are more than 1000 automated tests in Expertiza including a portion of feature tests, also known as functional tests, which can take longer to execute because the test framework needs to open a web page and mock the cursor to ensure that the different components on the web pages work as expected and (2) we ran these tests sequentially. To reduce the overall test execution time, we made several improvements: (1) turned on the "fail fast" option, that is to say, whenever there is a failed test, all later tests will stop executing and send the failed test information to the Travis CI bot immediately and (2) ran different kinds of tests in parallel, such as unit tests, integration tests, and feature tests. These optimizations successfully reduced the response time of the Travis CI bot from more than 18 to 8 min, which enabled students to receive more timely feedback.

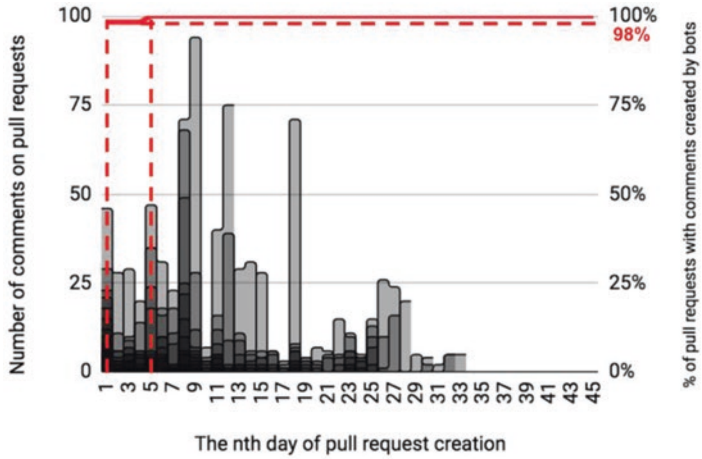
The majority of students thought that the inline comments given by the Code Climate bot were overwhelming. This was because we set up strict coding standards for the bot to detect, and also made the bot insert inline comments whenever it found code smells. However, having too many inline comments on one GitHub pull-request increased the page loading time and reduced code readability. Hence, we set up a threshold as the maximum number of inline comments that the bot could create on one pull-request. Whenever students fixed some issues, the Code Climate bot could post additional inline comments. In this case, the bot was able to continuously detect code smells from student-submitted code without creating too many comments.

Experimental Design and Results

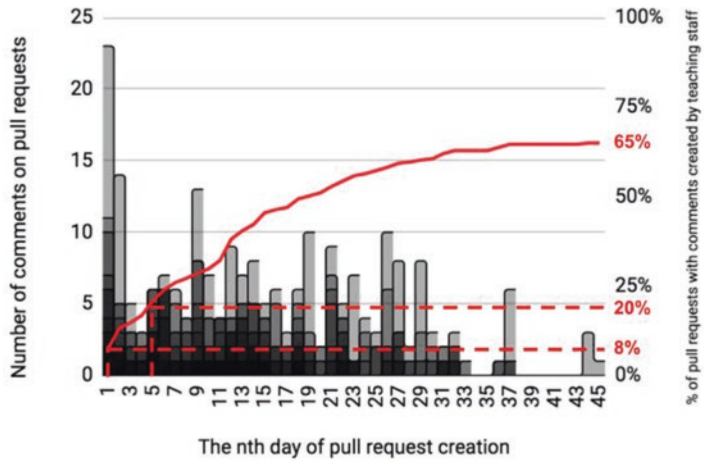
We implemented these three Internet bots in the fall 2018 semester. Student teams worked on projects and created GitHub pull-requests as deliverables. Bots added their comments to the pull-request pages, which were public on the Internet. That is to say, all team members were able to see these comments, and they could help each other to fix problems detected by bots.

To examine the effectiveness and efficiency of the Internet bots, we compared 57 GitHub pull-requests created by students in the fall 2018 semester and 339

[24] https://en.wikipedia.org/wiki/Regular_expression



(a)



(b)

Fig. 7 Timing of comments created by bots in the fall 2018 semester (**a**) and created by teaching staff in previous semesters (**b**) (Hu and Gehringer 2019)

pull-requests created in previous semesters back to the fall 2012 semester. We examined three aspects: (1) the response time of Internet bots and teaching staff, (2) code quality, and (3) the automated test pass rate. All 396 pull-requests were contributed by student teams with 2–4 team members.

To check the response time differences between Internet bots and teaching staff, we tallied the comments and their corresponding creation dates in pull-requests. Figure 7 demonstrates the comments generated by bots in the fall 2018 semester and those created by teaching staff in previous semesters. The *x*-axes represent the *n*th day of pull-request creation. The *y*-axes display the number of comments on pull-requests. Each bar represents the number of comments created on one pull-request for a particular day. To display the frequency of comment creations on different pull-requests, we showed each bar with 30% opacity. In this case, darker colors mean that more comments were created.

The red solid lines in Fig. 7a, b represent another metric—the percentage of pull-requests with comments created by either bots or teaching staff. From Fig. 7a, we found that Internet bots commented on 98% of pull requests on the first day of pull-request creation and that percentage reached 100% on the fifth day of creation. This is because the submitted code of one team conflicted with the Expertiza codebase in the first few days, which prevented the bots from providing feedback on their code. After they fixed the conflict, the bots could review and comment on their submitted code. Conversely, teaching staff only commented on 8% of pull-requests on day 1 and 20% of pull-requests on day 5. The percentage reached only 65 in the end, which means that around 35% of pull-requests did not receive any comments from teaching staff. Therefore, we conclude that Internet bots can provide more instant feedback in the form of GitHub pull-request comments than teaching staff.

We examined the code-quality differences between pull-requests in the fall 2018 semester and those in previous semesters by tallying the number of Expertiza-specific guideline violations. Results indicated that there was a significant difference in the number of guideline violations between the two groups of pull-requests (Hu and Gehringer, 2019). The Danger bot was associated with a significant reduction in guideline violations.

To analyze whether the Travis CI bot can help student teams achieve a higher test pass rate, we constructed a contingency table (Table 3). Due to conflicts between the current code base and code submitted by students several years ago, we did not obtain the test pass rates for all pull-requests. We conducted a Chi-square test. The result was that there was no significant difference in the test pass rate between the fall 2018 semester and previous semesters (Hu and Gehringer, 2019). Consequently, the Travis CI bot did not help student teams achieve a higher test pass rate by displaying the excerpted test execution results. Moreover, we compared the number of code smells between these two groups of pull-requests. We found that with the presence of the Code Climate bot, the code smells in student submissions have decreased by 60% (Hu and Gehringer 2019).

Table 3 Contingency table for tests pass rate

	Test pass	Test fail	Total
Previous semesters	149	107	256
Fall 2018 semester	21	25	46
Total	170	132	302

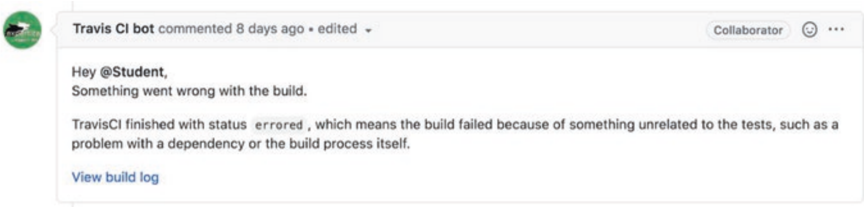


Fig. 8 A pull-request comment created by the Travis CI bot when something failed unrelated to the tests

In summary, the Danger bot is associated with a significant 39% decrease in system-specific guideline violations, and the Code Climate bot is associated with a significant 60% reduction in code smells. Nevertheless, the Travis CI bot did not help student-submitted code pass automated tests. After discussing with students, we figured out that many students still preferred to look at the raw text execution results regardless of the excerpted information provided by the bot. There are at least two reasons. First, students prefer to read the text execution results presented with terminal-like color coding and keyword highlighting instead of the plain text provided by the bots. Second, if no tests can be executed due to errors, there will be related error messages in the raw text execution results, but the bot can only provide the very limited information shown in Fig. 8.

We plan to upgrade the functionality of bots, for instance, (1) to make the Danger bot locate the particular file and line of code for each guideline violations and help students have a better understanding of the issues in their code; (2) to make the Danger bot and Code Climate bot support two-way communication. When students think the comments provided by bots are inaccurate, they can raise an appeal for one or more guideline violations and ask the bots to notify teaching staff to do a manual code review. If teaching staff confirm that some issues mentioned by bots are false positives or can be ignored in particular cases, they can tell bots to bypass those issues in the future code reviews.

Danger Bot 2.0

We introduce the Danger bot 2.0, which is the next generation of the Danger bot. The biggest enhancement of the Danger bot 2.0 is that it supports two-way communication between humans and bots. We designed and implemented an instruction set for the Danger bot 2.0.

Currently, there are four commands in the instruction set, namely `rerun`, *dispute*, `cancel`, and *confirm*.

The `rerun` command is used to make the bot to analyze the code for another round to check whether the system-specific guideline violations provided by the bot are deterministic. The `dispute` command is used when students notice that some

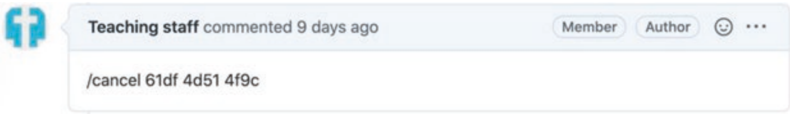


Fig. 9 A pull-request comment with command and parameters

Table 4 An example of command sequence

Timestamp	Author	Command
T1	Student 1	`/dispute v1 v2 v4`
T2	Teaching-staff member 1	`/cancel v1 v3`
T3	Teaching-staff member 2	`/confirm v4`
T4	Teaching-staff member 2	`/cancel v2 v4`

guideline violations noted by the bot are not accurate. Then they are able to dispute one or more violations. Immediately after students raise the dispute, the teaching staff will be notified. After conducting a manual code review, the teaching staff can either reject or accept the student's claim. If the teaching staff reject the claim, the bot will keep reminding students to fix the violation. On the other hand, if the teaching staff accept the claim, the bot will mark these violations as resolved and not check them again until further notice. The `cancel` and `confirm` commands are used to let teaching staff cancel and confirm one or more guideline violations proposed by the bot. It is worth noting that these two commands are independent of the `dispute` command. That is to say, even if students do not dispute any guideline violations, teaching staff are still able to cancel and confirm particular violations.

To implement these four commands, we set up an event listener on GitHub. Whenever a new GitHub comment was created, the event listener would send the data including command with parameters if any, comment author and comment timestamp to the server for the bots to parse. If the command is `rerun`, the bot will simply analyze the student-submitted code again and insert a GitHub comment with analysis results on the pull-request web page. If the command is `dispute`, the bot will notify the teaching staff and ask them to do a manual code inspection. The `cancel` and `confirm` commands are based on the `rerun` command. In addition, the bot needs to parse the parameters. Each parameter is a four-letter hash code[25] representing a universally unique identifier (UUID) of one guideline violation. Based on the command and parameters, the bot resolves or unresolves those violations accordingly after the code analysis process. For example, Fig. 9 is one pull-request comment with the `cancel` command and three four-letter hash codes as parameters separated by whitespaces.

The Danger bot 2.0 is stateless, which means the bot only fetches information from the current request, and it needs no information from previous requests nor does it store data in other places. Specifically, the bot relies on the comment

[25] Hash code is generated by a hash function, see https://en.wikipedia.org/wiki/Hash_function

messages, and the sequence of these messages, to decide which guideline violations should be canceled and which ones should be confirmed. The rule of thumb is that later commands override previous ones. Table 4 shows an example of how the sequence of the commands affected the final results provided by bots. T1–T4 are in increasing chronological order. Assume the bot has detected four guideline violations in the student-submitted code, namely, v1–v4. At T1, student 1 disputed violations v1, v2, and v4. At T2, after manual inspecting the code, teaching staff member 1 canceled the violations v1 and v3 (as false positives), and at T3, teaching staff member 2 confirmed the violation v4.

Between T3 and T4, students changed the code to fix problems. At T4, since teaching staff member 2 has canceled v2 and v4, all four violations have been canceled by the teaching staff. Additionally, the cancellation of v4 at T4 overrode the confirmation of v4 at T3. We also set different permissions for different commands to avoid the abuse of these commands; both students and teaching staff are able to use the `rerun` command, but only students can use the `dispute` command, and only teaching staff can use the `cancel` and `confirm` commands.

Table 5 is a concrete example along with the corresponding explanations on how to use these commands and how these commands affect the user interface.

In summary, these four commands enable the Danger bot 2.0 to support two-way communication between humans and bots. In addition, the teaching staff can adjust the decisions made by bots and avoid misleading students due to false-positive messages given by the bots.

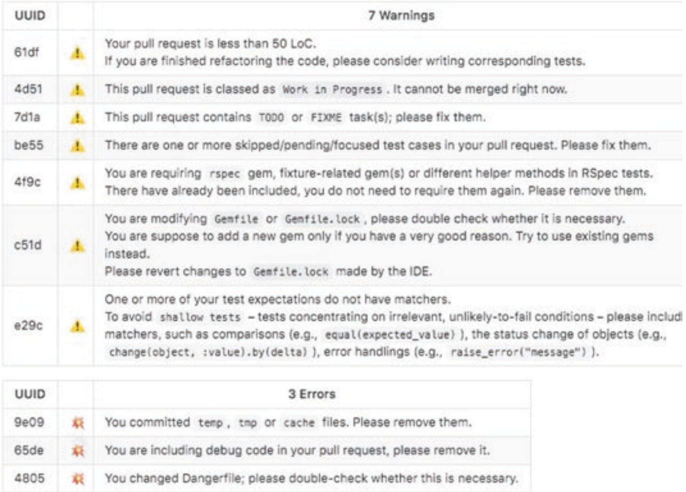
Conclusion and Future Directions

This chapter has introduced several digitally mediated tools, including test skeletons, an IDE plugin named Activity Tracker, and Internet bots, which can improve student programming and the code-review process, and facilitate high-quality team-based programming projects.

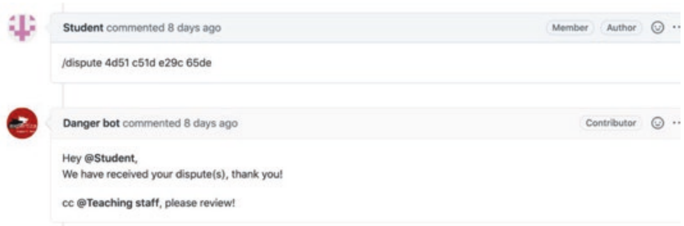
Before these tools appeared, it was difficult for students to (1) understand what kind of tests are required and (2) receive immediate feedback about their submitted code. Moreover, it was also hard for teaching staff to (1) get the information about student programming steps and obtain a comprehensive understanding of student programming activities during the project and (2) provide timely feedback on student-submitted code at any time.

With the help of these digitally mediated tools, all the abovementioned difficulties can be resolved or mitigated. With test skeletons, students can better understand what kind of tests are needed. With the help of the Activity Tracker, the teaching staff can understand student programming steps and help students improve the programming activities accordingly. Internet bots can reduce the workload of teaching staff by promptly pointing out system-guideline violations, test execution results,

Table 5 A use case of the Danger bot 2.0

<table>
<tr><th>Comments created by the Danger bot 2.0</th><th>Explanation</th></tr>
<tr><td>

UUID		7 Warnings
61df	⚠	Your pull request is less than 50 LoC. If you are finished refactoring the code, please consider writing corresponding tests.
4d51	⚠	This pull request is classed as `Work in Progress`. It cannot be merged right now.
7d1a	⚠	This pull request contains `TODO` or `FIXME` task(s); please fix them.
be55	⚠	There are one or more skipped/pending/focused test cases in your pull request. Please fix them.
4f9c	⚠	You are requiring `rspec` gem, fixture-related gem(s) or different helper methods in RSpec tests. There have already been included, you do not need to require them again. Please remove them.
c51d	⚠	You are modifying `Gemfile` or `Gemfile.lock`, please double check whether it is necessary. You are suppose to add a new gem only if you have a very good reason. Try to use existing gems instead. Please revert changes to `Gemfile.lock` made by the IDE.
e29c	⚠	One or more of your test expectations do not have matchers. To avoid `shallow tests` – tests concentrating on irrelevant, unlikely-to-fail conditions – please includ matchers, such as comparisons (e.g., `equal(expected_value)`), the status change of objects (e.g., `change(object, :value).by(delta)`), error handlings (e.g., `raise_error("message")`).

UUID		3 Errors
9e09	✖	You committed `temp`, `tmp` or `cache` files. Please remove them.
65de	✖	You are including debug code in your pull request, please remove it.
4805	✖	You changed Dangerfile; please double-check whether this is necessary.
</td><td>An initial pull-request comment created by the danger bot 2.0
Compared with the comment created by the previous version of the bot (Fig. 3), we added a UUID for each guideline violation to facilitate these commands identifying different violations</td></tr>
<tr><td>

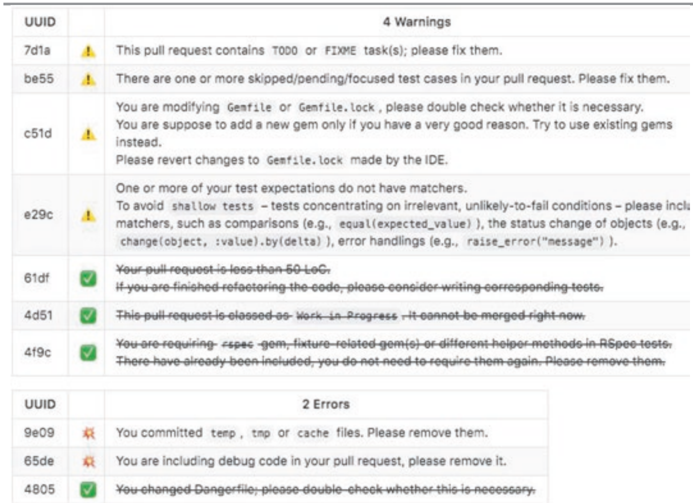
Student commented 8 days ago · Member · Author

/dispute 4d51 c51d e29c 65de

Danger bot commented 8 days ago · Contributor

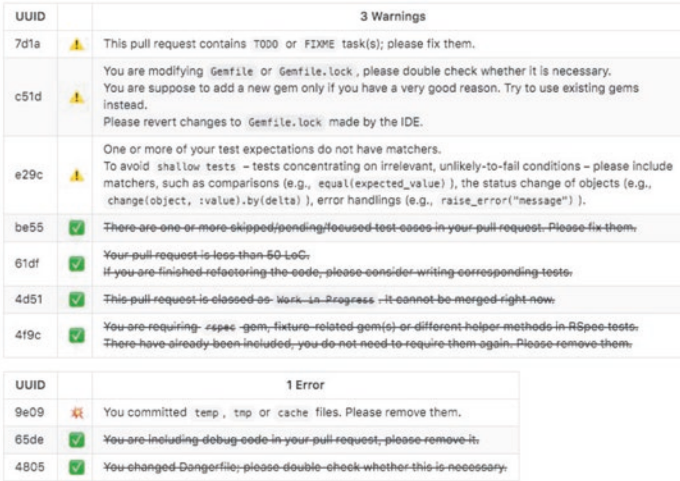
Hey **@Student**,
We have received your dispute(s), thank you!

cc **@Teaching staff**, please review!
</td><td>When students add a new dispute comment */dispute 4d51 c51d e29c 65de*, the bot will immediately reply to students and notify the teaching staff to review their code and especially check for violations associated with those UUIDs</td></tr>
</table>

Comments created by the Danger bot 2.0	Explanation
	After inspecting student-submitted code, the teaching staff can cancel one or more unresolved violations by inserting a new comment on the pull-request page, e.g., */cancel 61df 4d51 4f9c 4805* This cancels violations associated with those UUIDs, with strikethrough messages and green check icons in front of the message. Note that teaching staff can cancel zero or more guideline violations disputed by students, along with other unresolved violations that they think can be bypassed

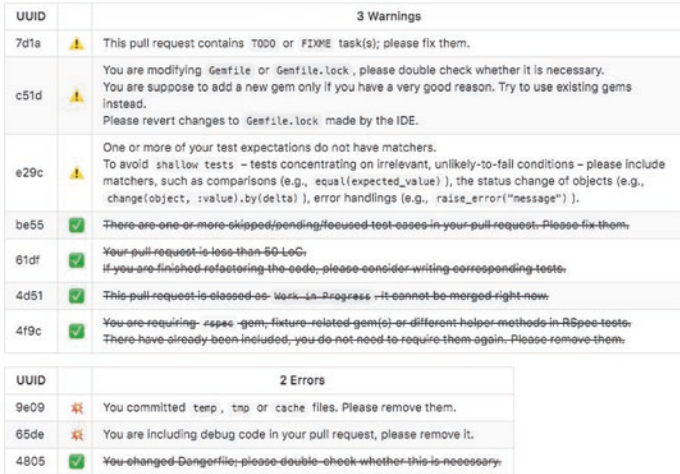
(continued)

Table 5 (continued)

Comments created by the Danger bot 2.0	Explanation
	After students submit new code changes, the bots check the code again and mark some guideline violations (be55 and 65de) as resolved

UUID		3 Warnings
7d1a	⚠	This pull request contains `TODO` or `FIXME` task(s); please fix them.
c51d	⚠	You are modifying `Gemfile` or `Gemfile.lock`, please double check whether it is necessary. You are suppose to add a new gem only if you have a very good reason. Try to use existing gems instead. Please revert changes to `Gemfile.lock` made by the IDE.
e29c	⚠	One or more of your test expectations do not have matchers. To avoid `shallow tests` – tests concentrating on irrelevant, unlikely-to-fail conditions – please include matchers, such as comparisons (e.g., `equal(expected_value)`), the status change of objects (e.g., `change(object, :value).by(delta)`), error handlings (e.g., `raise_error("message")`).
be55	✅	~~There are one or more skipped/pending/focused test cases in your pull request. Please fix them.~~
61df	✅	~~Your pull request is less than 50 LoC. If you are finished refactoring the code, please consider writing corresponding tests.~~
4d51	✅	~~This pull request is classed as `Work in Progress`. It cannot be merged right now.~~
4f9c	✅	~~You are requiring `rspec` gem, fixture-related gem(s) or different helper methods in RSpec tests. There have already been included, you do not need to require them again. Please remove them.~~

UUID		1 Error
9e09	💥	You committed `temp`, `tmp` or `cache` files. Please remove them.
65de	✅	~~You are including debug code in your pull request, please remove it.~~
4805	✅	~~You changed Dangerfile; please double-check whether this is necessary.~~

Comments created by the Danger bot 2.0	Explanation
	The teaching staff always have the right to bypass the decision of the bot by adding a new comment with message */confirm 65de*; then that violation cancelled by the bot becomes unresolved again

and code smells in student-submitted code. Besides, the two-way communication between humans and bots further calibrates the suggestions provided by the bots.

We believe that the future direction of digitally mediated tools is automation. This is because although we have already implemented these tools, many manual steps are still involved. For instance, we have to manually create the test skeletons to help students write better tests, and we have to involve manual steps to process the student programming steps and analyze how good students adhere to the test-driven approach. If we can introduce more automation to digitally mediated tools, they can further benefit students without too many interventions from the teaching staff.

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Part III
Analytics and Social Perspectives of Digitally-Mediated Team Learning

Designing Analytics to Support Team Learning

Qiujie Li, Yeonji Jung, Alyssa Friend Wise, Sophie Sommer, and Victoria G. Axelrod

Abstract Team learning has become an essential activity in both professional and educational contexts. Learning analytics offers promising opportunities to support team learning by making information about group processes available to teams in real time to help them learn how to interact more productively. The design of team analytics requires three sets of critical decisions: the choices of *metrics*, the ways in which these metrics are *presented*, and how the analytics are *implemented*. This chapter describes four guiding principles for navigating this decision space in ways that produce relevant, understandable, and actionable analytics to support team learning. Application of the principles is illustrated in a design case of creating analytics for a discussion-based online course. The chapter concludes by describing the uptake of and student responses to the analytics in a pilot implementation and considering lessons learned for the design of team learning analytics.

Introduction

Tasks today are increasingly taken on by groups of people in various configurations commonly referred to as teams. Teams are an important venue for learning (whether an explicitly stated goal or not) where people develop new knowledge about the tasks they are working on as well as how they work together. While the term "team" has come to be used colloquially in professional contexts for any group doing work together, not every workgroup constitutes a team (Katzenbach and Smith, 1993). The same is true in educational contexts, where groups working together are often labeled "collaborating," where they might be simply cooperating or working in parallel (Dillenbourg, 1999). The difference in both cases lies in efforts to develop

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collective knowledge, or following Roschelle and Teasley's (1995) definition of collaboration, to engage in ongoing negotiation of meaning to maintain a shared understanding of the problem at hand.

While there is a rich history of work documenting and investigating team processes for research purposes (e.g., Chen and Huang, 2019; Edmondson et al., 2007; Senge, 1990; Wise and Cui, 2018), efforts to make information about these processes available to the teams themselves have been limited until recently. Work on group awareness tools (Bodemer et al., 2018) focused primarily on developing specialized applications that visualize *social processes* (who is interacting with who) and *knowledge states* (who knows what) as part of the communication interface itself. What has often been missing is the opportunity to step away and reflect on information about *group cognition* (Stahl, 2020) that teams can use to understand and improve the ways they build knowledge together. The recent development of learning analytics as a technology dedicated to leveraging data about learning processes to improve them (Siemens et al., 2011) offers exciting opportunities to expand the information available to teams. But with *possibilities* come *choices* about what data to show to whom, in what form, and at what point in time. These decisions influence whether the data provided is seen as useful and impacts subsequent action. This chapter provides support for navigating this decision space by offering a set of four guiding principles for team analytics design and providing an example of their application to create an analytics solution in a particular learning context. The chapter concludes with a discussion of how the designed analytics were received in a pilot implementation and lessons learned for designing analytics to support team learning.

Designing Analytics to Support Team Learning: Conceptualization and Guiding Principles

The central idea of using analytics to support team learning is that feeding information about how a team is functioning (practically, socially, and cognitively) back to the team can help its members (individually and collectively) evaluate and improve these processes. Efforts to do so are currently bolstered by advances in technologies for data generation, techniques for data analysis/visualization, and an improving ability to return feedback based on these processes in a timely fashion. On the data front, as more and more team interactions are mediated by technology, records of clicks, text, audio, and video are generated automatically. Data in face-to-face contexts is becoming easier to acquire as well with the improvement in various sensors for tracking gestures, eye movement, and recording multiple audio and video feeds (Ochoa, 2017). However, as fine-grained data "footprints" become more available across time and space, we are faced with important choices in distinguishing what is *useful* to track out of everything it is *possible* to track. In addition, the effectiveness of analytics relies on whether students engage with the information provided, how they make sense of the information, and whether and what actions they take based on it (Wise et al., 2016; Wise and Vytasek, 2017).

To this end, the design of analytics for team learning can be conceptualized as consisting of three distinct, but interrelated, sets of decisions. First, there is the choice of metrics to determine what information will be shared with team members. These decisions include what quantities will operationalize the valued qualities of team learning (e.g., "level of engagement" might be indexed (simplistically) by "number of discussion posts") and what statistics to provide about them (e.g., total, mean, median, or range). Second, there is the choice of visual displays to determine how to present the metrics. These decisions include the organization of different informational elements, whether and how to use graphical, numerical and/or textual presentations, and additional interpretational aids to support sense-making. Finally, the design of the implementation of the analytics is obtained. This includes choices about when and how to deliver the analytics to team members and any pedagogical supports to introduce the analytics into the learning situation and guide team members' use of the analytics. Four principles can guide making these sets of decisions.

Principle 1: Align analytics with valued team learning qualities. Analytics to support team learning need to communicate what is valued in team processes and function as a signal to help team members identify which elements of their participation are and are not aligned with expectations and the ways they can alter their engagement to improve team learning (Fincham et al., 2019). This can be done by connecting "clicks to constructs"—identifying high-level valued qualities of team processes for which lower-level data features can act as proxies (Wise et al., in press). Connecting available data to valued qualities can be done logically or empirically. To make connections logically, high-level constructs are defined such that data features can be engineered to represent them. For example, the construct of a team leader could be conceptualized as the person who commands the most attention from others and thus be represented by a social network centrality metric[1] of who is most spoken to (or looked at). To make connections empirically, constructs are operationalized so they can be identified (by humans) in sample teams with machine learning then used to extract data features that align with their presence. For example, researchers might use a rubric to assess the level of cognitive engagement of online discussion messages and then identify textual features (such as expressions of positive emotion) that predict its presence (Farrow et al., 2020). Important constructs for team learning can also be identified at the group level, for example, the uptake of ideas between people as an indicator of shared understanding (Suthers et al., 2010).

Principle 2: Present analytics in ways that support sense-making and action. Making sense of analytics is not a straightforward process (Wise and Jung, 2019). Thus metrics need to be presented in ways that guide team members in interpreting the metrics in relation to the local learning context (Wise et al., 2016). Visualizations should communicate information and display patterns in a rigorous, accurate, and

[1] Such as in-degree

intuitive way (Chen, 2010). Limiting the visual density of information, as well as the use of technical language, can help reduce the cognitive load of interpretation imposed on team members. Additionally, guidance can be provided to inform team members about effective ways to read and interpret analytics. In addition to supporting sense-making, analytics need to be designed to promote actions that improve team processes (Clow, 2012). Thus, the provision of analytics needs to guide team members in asking meaningful questions of the analytics, figuring out implications of the answers, and strategizing what to prioritize in their actions toward optimized team learning (Yilmaz and Yilmaz, 2020).

Principle 3: Implement analytics incorporated into team learning practices. To foster effective action taking, the use of analytics needs to be incorporated into team learning practices in a way that team members perceive them as relevant and use them regularly (Wise et al., 2014). Guidance can be provided to show how the analytics aligned with the desired process of the team and to position the use of analytics as part of the team learning processes. With the promise of using learning analytics to support self-regulation, it is particularly important to frame the analytics as a tool to empower team members as opposed to control them (Slade and Prinsloo, 2013). Specifically, guidance can be provided to support team members to set up personal and collective process goals, use the information provided as feedback to evaluate their progress toward these, making informed decisions about future actions. Finally, space for dialogue around the use of the analytics can be created to provide a channel for communication and negotiation as a complement to support user agency and to encourage reflection on and responding to the analytics (Wise, et al., 2016; Yilmaz and Yilmaz, 2020).

Principle 4: Include analytics from both the individual and group perspectives. Team learning is a group process in which individual members share ideas, negotiate (dis)agreement, and construct shared understandings (John-Steiner and Mahn, 1996). While learning analytics have traditionally been developed primarily with attention to individuals, the team learning context requires consideration of the group as a whole as well. This taps into the potential for data to support not just self-regulation of learning ("how am *I* contributing to the team and what can *I* do to improve this?") but socially shared regulation of learning as well ("how are *we* performing as a team and what can *we* do to improve this?") (Järvelä et al., 2015). To fully support team learning through analytics, both individuals and the collective should be considered as the *objects of*, and *audience for*, analytics. This guideline spans all three sets of decisions in analytics design. First, it requires metrics about qualities of individuals as well as those of the group as a whole. For example, the coherence of dialogue addresses the extent to which the different comments of team members make sense with respect to one another and is an important characteristic of teamwork that only exists at the group level. In addition, the presentation of the analytics needs to help students make sense of the relationships between individual- and group-level metrics and consider how to adjust their own and the team's behavior to achieve shared goals. Finally, opportunities for individual reflection and group dialogue around the analytics can be created to facilitate interpretation and response at both levels.

This section has described guiding principles for designing analytics to support team learning in general; however, the creation of any team analytics solution needs to be specific to a locally relevant vision of teamwork. To illustrate this process of analytics creation as *design*, the remainder of this chapter describes the application of the principles described above to develop analytics for one particular context: a small online discussion-based undergraduate course on organizational behavior.

Designing Analytics to Support Team Learning Exemplar: The Case of a Discussion-Based Online Course

Context for the Analytics: Course, Students, Team Learning Situation, and Data

The context for analytics design was an online undergraduate course on organizational behavior designed for a working student population. All course assignments were asynchronous and could be completed on students' own schedule within a weekly timeline. To generate student engagement in this format, the instructor of this course utilized the discussion forum in the LMS[2] course site as the primary channel for student interaction and designed all learning activities to take place there.

The goals of the discussion activities were for students to engage with and demonstrate their understanding of course content by sharing their views, being exposed to diverse ideas, and reflecting on their perceptions; to foster the development of a learning community among the students; and to give students the central responsibility for their learning. In service to these goals, the discussions were peer-led dialogues on course readings, videos, and lecturettes centered around key questions, where the responsibility was on the students, not the faculty member, to drive participation. Specifically, each week, two students were asked to create at least four discussion questions and facilitate fellow class members' engagement in the forum around them. Detailed instructions for how to participate in the discussion activities were provided, and discussion questions were submitted in advance for faculty review. Facilitators were asked to be active throughout the week to guide the discussion, with the faculty following along to send direct messages or group prompts as needed. At the end of the week, each facilitator was required to write an executive summary covering the major themes of the forum discussion and key learning for themselves.

Rich student engagement is the key to the success of discussion forum activities. The following expectations (aligned with a grading rubric) were posted in the first week of the course to guide students towards this goal. First, students were expected to actively respond to at least four of the weekly questions posted, making their first post no later than Wednesday and second before the end of Saturday (to avoid the

[2] Learning Management System

previously observed pattern of students posting primarily the day before the discussion closed). Second, in their responses students should demonstrate that they have command of the topical issues. Finally, students were encouraged to express diverse views regarding the topical issues and expand upon these with classmates through interactive dialogue.

Data from two sources were available for designing the analytics. The primary data source was log-file data extracted directly from the forum tool for each post which included: post id, thread id, parent post id, ids of users who created and modified the post, post creation and modification date and time, number of views the post received, titles of the posts, and post text. This was supplemented by the instructor with information not available directly from the system: names of discussion forum facilitators, topics of discussion, and assigned readings.

Goals for Introducing Analytics

Learning analytics were incorporated into the course to serve two purposes. First, they were provided to help students improve their engagement with the discussion forum. Striving to meet the course expectations without the benefit of feedback on the process of learning leaves a gulf between stated expectations and the eventual evaluation. The concepts and tools of learning analytics give students a way to understand how they operate as part of a team that can serve them throughout the course. Second, related to the subject of the course, organizational issues evolve from interactions and relationships between people, for which learning from successful and failed collaboration is a key to moving forward. Providing students with analytics on their discussion activities gave them firsthand experience with both the benefits and the challenges of using analytics for human performance measurement and feedback in organizations.

Team Analytics Design

Part 1: The Metrics

The first step in designing analytics to support team learning is to create a set of metrics that can characterize team processes over time. This work drew on two principles—*align analytics with valued team learning qualities* and *include analytics from both the individual and group perspectives.* We began by articulating the valued qualities of discussion-based team learning collaboratively with the course instructor through a dialogue grounded in the goals, design, and assessment of the discussion activity described above. Three dimensions of valued qualities of team discussion emerged: the extent to which the team *participated* in the discussion, the levels and forms of their *interactions,* and the *thoughtfulness* of their posts. The dimensions were considered at both individual and group levels and compared with the available data sources to develop a list of specific valued qualities with corresponding metrics. Further, the specific statistics to provide for each metric were determined, taking into account practical and pedagogical considerations. Since the discussion activities were organized by weeks, it was established early on that the metrics would be calculated for the week as a whole to provide students with information about each team activity. The development of the metrics in each of the three dimensions are described below and summarized in Table 1.

Table 1 Valued qualities and metrics designed for three dimensions of team discussion

Valued qualities	Metrics indexed for each quality	Target of metrics
Quality dimension: Participation		
Active post and reply creation	Total number of initial posts and replies by question	Group and individual
Timely and regular posting	Timing of posts	Group and individual
	Percent of posts on the most active day of the week	Group
Sufficient information in the post	Median, minimum, and maximum lengths of posts	Group and individual
Quality dimension: Interaction		
Frequent, decentralized, and reciprocal interaction	Number of connections between team members	Group and individual
	Percentage of reciprocal connections	Group and individual
	Overall level of centralization of the connections	Group
	Total number of replies made to and received from specific individuals	Individual
	Total number of views and responses to each individual's most viewed post	Individual
Showing position to others' arguments	Median, minimum, and maximum numbers of posts with words indicating agreement	Group and individual
Asking questions	Median, minimum, and maximum numbers of posts with questions	Group and individual
Quality dimension: Thoughtful ideas		
Aligning the discussion with the weekly course topics	The list of weekly course topics indicated in the syllabus	Group
	Word cloud of common bigrams	Group
Sharing thoughts	Median, minimum, and maximum numbers of "idea sharing" words	Group and individual
Backing up ideas with reasoning	Median, minimum, and maximum numbers of "giving reasons" words	Group and individual
Backing up ideas with references	Total number of references to assigned readings	Group and individual

Participation, operationalized in this course as making *contributions* to the facilitator's questions and *responding* to the ideas shared by other team members, is a baseline requirement for team learning. As stated in the discussion instructions, students were expected to participate by creating posts in response to at least four of the weekly questions. This was relatively straightforward to index from the log-file data since it related to the question of "how much" and was calculated as the total number of posts and replies made by each team member as well as the class as a whole, segmented by the facilitators' questions.

Second, discussion participation needs to be *timely and regular* so that team members can engage with each other's posts in a reciprocal manner (Chen and Huang, 2019). Students in this course were required to make their first post no later than Wednesday and second post before the end of Saturday. The question of when posting occurred also required a low-level inference from the log-file data, which directly recorded the time and date when posts were submitted. To help students monitor their posting activities in relation to the two weekly deadlines, the posting dates were used to compute and display the distribution of which days throughout the week each individual made posts. At the group level, in addition to the distribution of all the posts made by the class in a week, the highest activity day for the entire class in a given week was also reported to help students monitor class-wide trends and disincentivize cramming posts close to the deadline.

Finally, for a rich discussion to occur, posts should contain *sufficient information* about the topics to stimulate and advance team conversation (Dennen, 2001). The discussion instructions asked students to elaborate their understanding of the topic by providing more than just a simple opinion (e.g., "I (dis)agree") to add additional perspectives, for example, by making a critique or connecting to other relevant topics. Assessing the novel informational content of a post can be complex because different words and phrases can carry variable amounts of information, and this is highly dependent on the specific topic at hand. Determining whether new information is being contributed depends not only on the contents of a post but also the contents of prior posts. From a process perspective, while linguistic metrics can index information in the words of a post through computational text analysis (e.g., by examining concreteness or coherence, see Graesser et al., 2004), students may find these difficult to interpret and/or not trustworthy, and thus not take any action upon them (Clow, 2012). In contrast, post length can be used as a simple (though more distal) proxy, as longer posts generally tend to contain more information. Indeed, post length has been found helpful in supporting students to improve the richness of the conversation (e.g., Wise et al., 2014). Thus, the median, minimum, and maximum numbers of words used per post were calculated for both individual students and the class as a whole. The median was used as a measure of central tendency rather than the average to reduce skewing by posts with extreme lengths (e.g., specifically those including long quotes from the materials). The minimum and maximum numbers were included to provide a sense of the range of post lengths and help students evaluate the levels of consistency in their posting behavior. The main purpose of the post length metric was thus to offer a low-level baseline for students to monitor if their posts were repeatedly too short to contribute informational content to the discussion.

Interaction refers to the extent and manner through which team members connect with each other and each other's ideas in a discussion. With the goal of exchanging ideas, it is important for a discussion to involve frequent interaction among team members (Dawson, 2006). In the discussion instructions, students were asked to reflect upon others' posts and actively respond to the posts to meaningfully expand the discussion. *Reciprocal interaction*, in which team members reply back and forth to one another, is particularly beneficial in supporting the continuation of the conversation and thus in-depth and constructive discussion (Anderson, 2008). Another goal of the class discussion is for students to gain diverse perspectives. Therefore, it is critical that the discussion is *distributed* across group members rather than centralized around a small number of individuals.

Social networks are commonly used to represent team interactions and can be used to support shared-social regulation to change the flow and structure of discussion when needed (Chen et al., 2018; Dawson et al., 2010; Ferguson and Shum, 2012). One key decision in creating social networks is how to define a connection (tie) between team members (nodes in the network). This can be done narrowly based on one person directly replying to another or broadly based on two people participating in the same thread of discussion. Following the findings of Wise and Cui (2018) that thread co-presence ties can lead to artificial inflation of connectivity, ties between team members were defined based on direct replies. The resulting network diagram showed the presence, strength, and directionality of the connections to inform students about the frequency of interaction and help them identify reciprocal interaction between team members. In addition, the network structure visually indicated the extent of centralization of the discussion based on whether it resembled a hub-and-spoke or spiderweb configuration.

While network diagrams could effectively communicate group-level information, two additional metrics were supplementally presented at the individual level. First, the number of replies made to and received from specific peer members was provided to allow students to monitor their personal network development. Second, each student's most engaging post (operationalized as the post that received the most views and replies) was displayed to highlight their contribution to stimulating class interaction and draw their attention to posts that were successful in generating interaction.

Going beyond the quantity of interaction to its quality, the discussion instructions emphasized that posts should reflect on prior contributions and expand the discussion in a meaningful way. Such expansion of discussion can be achieved as team members relate their comments to others in two ways. First, students can *show their position with respect to others' arguments* (e.g., agree or disagree), to demonstrate that they are actively evaluating the points made by their classmates. Second, students can *ask questions* in the posts to prompt other members to reflect on their ideas and stimulate additional thoughts (Nussbaum et al., 2004).

Natural language processing (NLP) can be applied to the text of discussion posts to generate indicators of the above-mentioned valued forms of interaction. NLP methods for the generation of text indicators may fall into three categories: dictionary-based approaches (which identify occurrences of a predetermined library of terms), rule-based approaches (which apply expert-driven rules based on the syntactic structure of the text and the semantic properties of the words), and classification approaches (which use machine learning to label data based on models built on annotated training text data) (Ullmann, 2015). We chose to use the dictionary-based approach since it does not require prior training and offers accessible interpretation for students, specifically applying the Linguistic Inquiry and Word Count package (LIWC2015). This software has been widely applied in the higher education context, due to its theoretical grounding in psychological constructs and relatively straightforward interpretation. LIWC2015 was used to index *positioning arguments* by identifying terms related to agreement (e.g., agree, yes, okay), the most relevant dictionary available. An index for disagreement was not available, leaving a gap in the metrics design. *Question posts* were identified as posts with sentences ending in a question mark.

Finally, **thoughtful ideas** refers to the content of discussion contributions. This can be considered in terms of both what ideas are discussed and how they are discussed. For the current context, discussions focused on weekly topics presented through readings, videos, and lecturettes. It is easy and common for online discussions to veer away from their original focus (Hewitt, 2003), thus information about how well *the discussion aligns with the intended topics* can be useful to help students keep the discussion on track. One way to address this issue is by using computational approaches such as topic modeling to reveal underlying themes in the discussion text and compare these with the assigned course topics. However, model calibration, specification of the optimal number of topics, and the need for interpretable topic labeling do not lend themselves easily to automation. A simplified solution is to display the most commonly used phrases in posts and the target weekly topics together for comparison. We chose to track the most common *bigrams* (i.e., pairs of consecutive written units), rather than *single words* (which did not provide enough contextual information) or *repeated phrases* (which were rare as students varied in their word choices and the sequences of using the words to express their opinions).

Considering how ideas are discussed, from an argumentation perspective, it is important that students not only take a position to *express their ideas* but also *substantiate them with reasoning* and *supporting sources* (Clark and Sampson, 2008; Wise and Hsiao, 2019). How often students express their opinions can be measured by the number of words indicative of "idea-sharing" (a LIWC2015 sub-dictionary including terms such as "think" and "consider"). The median, minimum, and maximum number of idea-sharing words per post were calculated and presented for each individual and the class. Second, backing up ideas with sufficient support can promote critical group discourse and can be achieved by *substantiating the ideas with reasons* and *references* (Gao et al., 2009). LIWC2015 was used to calculate the median, minimum, and maximum number of words related to "providing reasons" (another LIWC2015 sub-dictionary including terms like "because" and "therefore") per post for individual students and the class. Finally, the total number of times students referred to the assigned readings was calculated based on the mention of author names for individual students and the class. Total number was used instead of the average amount of references across posts because, unlike providing reasons, it was nor expected that students would need to make reference to the course readings in every post they made.

Part 2: The Presentation

Once the analytic metrics were decided on, the next set of decisions related to how to present these to students. While interactive dashboards are a common format for analytics presentation, research has shown that these can be overwhelming to navigate and challenges have been reported in getting users to access them in the first place (Jivet et al., 2017). In this initial application, we instead selected a digital report to be delivered weekly via an email link as a way to provide students with consolidated feedback on the different aspects of their team learning. The overall structure of the report followed the categories of metrics described above as a way to communicate to students the alignment described in the previous section, while the detailed sections of the report were designed following the principle to *present analytics in ways that support sense-making and action*. Following the principle to *include analytics from both the individual and group perspectives*, the report was also designed to prompt students to reflect on their own learning as well as the shared performance of the team. The process of building the report was iterative and collaborative between the learning analytics team and the course instructor. For each metric, we created multiple possible visualizations and associated text based on the guiding principles and held regular meetings to review and evaluate them. We also met with the course instructor to discuss potential issues and brainstorm ideas to create new versions of each visualization for the subsequent round of iteration. Below, we illustrate how this process was used to instantiate the metrics described above as a tangible report.

First, to *support sense-making*, we strove to communicate the chosen metrics in an accessible and interpretable way by considering the format (graphical/numerical/text), tone (language/vocabulary), and supports (additional information/context) provided in each section of the report. Graphs and figures were prioritized when possible and numerical summaries were used to provide supportive detail rather than large bodies of text (Mayer et al., 1996). For example, one section of the report was designed to communicate the distribution of discussion posts over the course of a week (see Fig. 1). The visualization provided students with an overarching view of the timeline of class participation to help students monitor their discussion contributions in the context of those made by team members. Individual student's posting activities were differentiated from other team members using a different marker shape. Below the figure, students were also provided with a single numerical summary at the group level—the day of the week with the most collective activity and the percentage of class-wide comments that were made on that day. This allowed

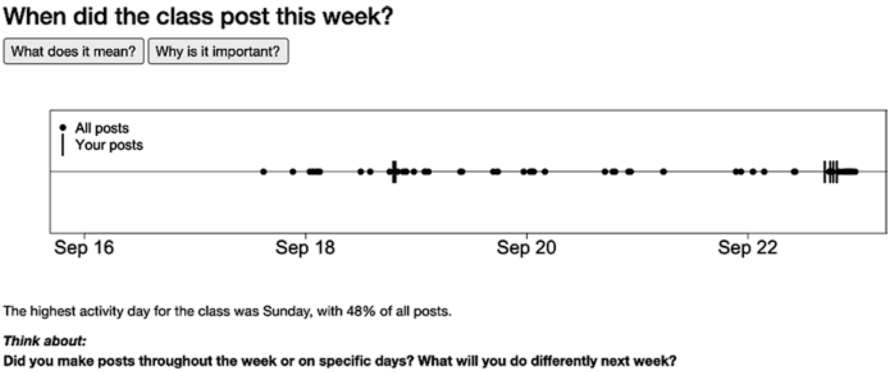


Fig. 1 Visualization of metrics of timely and regular posting

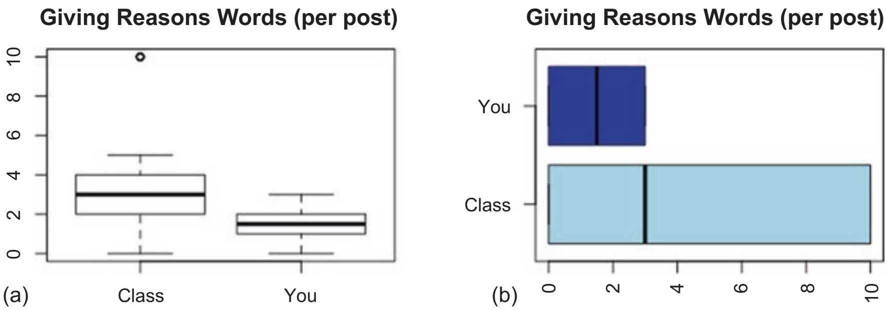


Fig. 2 (**a**) Initial and (**b**) updated versions of the visualization of giving reason words metric

team members to quickly identify whether the team crammed their posting activity near the deadline.

Our efforts toward reducing complexity extended to the creation of the graphical representations themselves. For example, the design of a visualization for the number of "giving reasons" words per post among the entire class started with a traditional box plot, which displayed minimum, first quartile, median, third quartile, and maximum of the data (Fig. 2a). However, in showing the visualization to students similar to those expected in the class (with a limited or nontechnical background), students reported that the plot, especially the quartiles, was confusing. The visualization was then simplified to a box covering minimum and maximum values with a line at the median (Fig. 2b).

In some cases, we chose a textual rather than a numerical presentation of information, specifically working to present relevant statistical concepts without using complex language. For example, network centralization is an unfamiliar term for which numerical values do not have intuitive meaning to many students. Thus instead of reporting numerical values (e.g., "This week's team centralization was 0.3"), a visualization of the network with an accompanying high-level textual explanation was provided (e.g., "This week's social network was relatively decentralized, with many connections between different people") (see Fig. 3). Cutoffs for the different categories (very decentralized, relatively decentralized, relatively centralized, very centralized) were determined using network graphs from the previous semester's offering of the course.

Finally, to support student sense-making, an additional interpretational aid was provided to explain how to read and interpret each visualization or statistic. To provide more seamless access to the support, instead of using a separated interpretation guide, we incorporated explanations of the meaning and importance of each metric directly into the report via two buttons that students could click: one to see an explanation about how to interpret the metric and one describing why it was important in the context of this class (see Fig. 4). This design reduced the amount of text on the page at any given time, while making it easy for students to access support when needed.

To *support actionability*, we sought to provide students with clear steps for self-reflection and ways to make improvements in their team learning. We embodied this idea as "think about" questions provided below each visualization, incorporating language within the report to prompt self-reflection about past contributions and

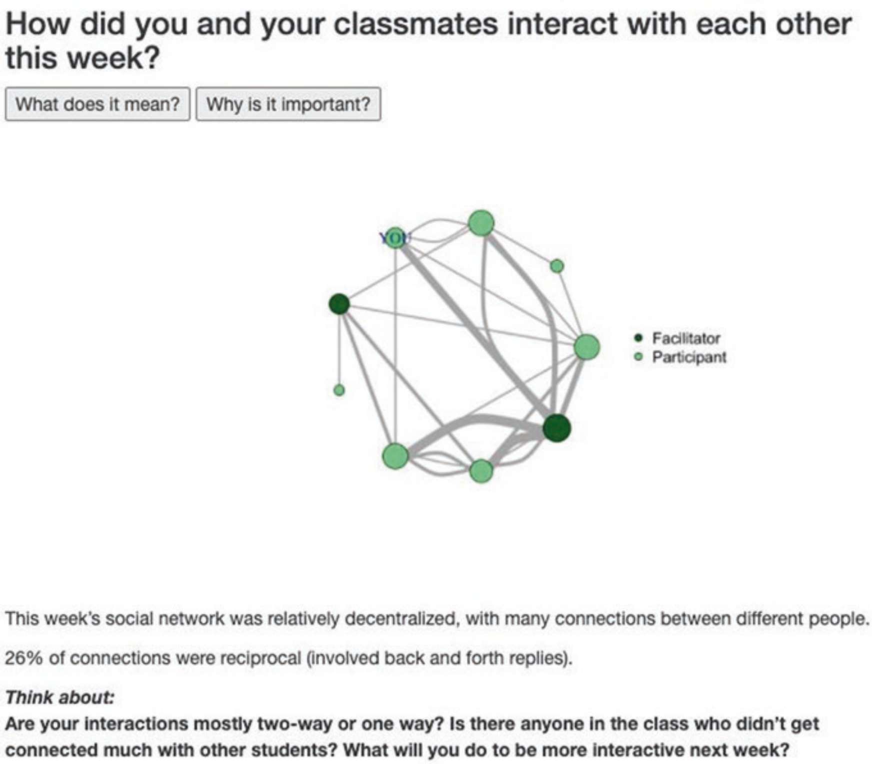


Fig. 3 Visualization and text related to the social network

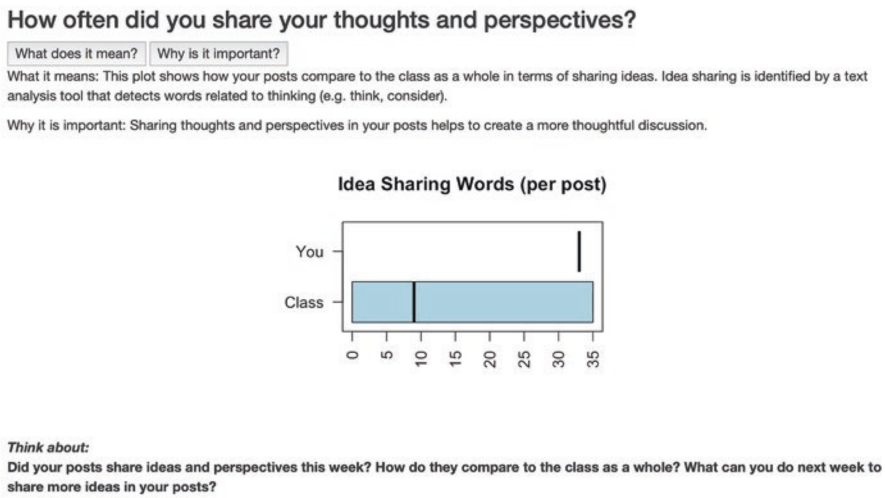


Fig. 4 Interpretation support embedded as clickable buttons in the report

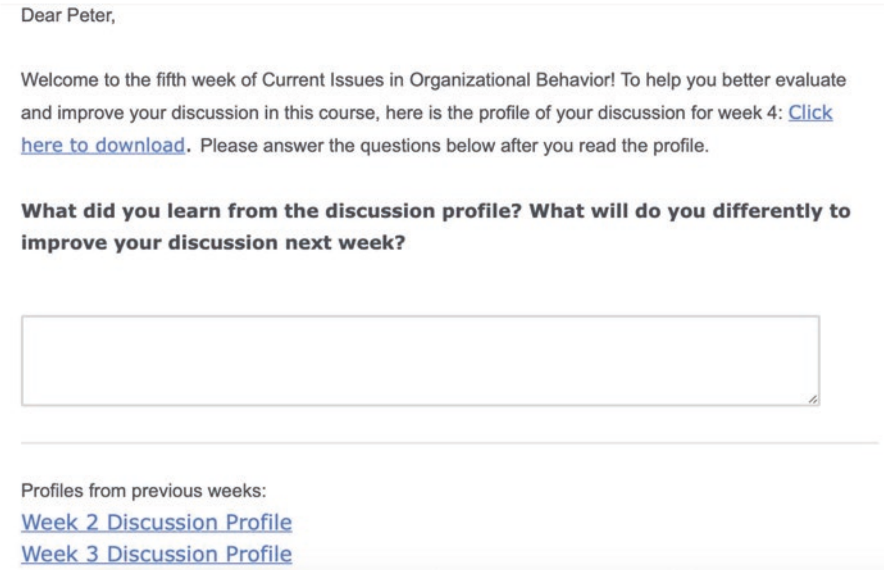
consideration of potential avenues for future action that would benefit the team (see Fig. 4). In designing these questions, we considered both the individual and group perspectives, developing multiple sets of questions for each visualization that prompted students to reflect on their individual participation (e.g., "Are your interactions mostly two-way or one way?"), the progress toward achieving team goals (e.g., "Is there anyone in the class who was not connected with other students?"), and what they could do to improve the discussion in the future (e.g., "What will you do to be more interactive next week?").

Part 3: The Implementation

Our final set of decisions were related to the implementation of the analytics in the course and followed two principles—*implement analytics incorporated into team learning practices* and *include analytics from both the individual and group perspectives*. We provided guidance about the use of analytics and student activities for both individual students and the class as a whole through pedagogical supports that framed the use of the analytic report in the larger structure of the course and the creation of opportunities for students to reflect on and respond to the analytics during the course (Wise and Vytasek, 2017).

To frame the use of analytics as an integral part of the team learning process, the instructor explicitly introduced the analytics report at the beginning of the course. Specifically, the instructor embedded a description of the analytics in the syllabus and sent an announcement in the first week to inform students about the availability of the weekly report. The announcement described the format and purpose of the report with suggestions for how to best benefit from it and also made clear the analytics would *not* be used for grading. The report was delivered along with a statement framing its goal to help students evaluate and improve their engagement in the discussion (see Fig. 5). In addition, each week, students could access not only their current report but also all the historical reports, allowing students to compare and look for changes over time. Finally, facilitators were asked to incorporate what they learned from the analytics about the discussion process and content quality into their executive summary, particularly reflecting on how the class performed as a learning community.

Creating opportunities for students to respond to the analytics can support actionability. Particularly, we designed spaces for students to reflect on the analytic report individually and as a group. At the individual level, the analytic reports were delivered along with prompts that encouraged students to think about and respond to what they learned from the analytics about their participation in the preceding week and how they could improve in the next week (see Fig. 5). At the group level, a separate discussion forum was set up for students to share ongoing thoughts and reflect as a group on all and any aspects of the weekly analytic reports. Students were specifically prompted to use this space to reflect on and discuss with each other the pros and cons of receiving analytic information on their team learning processes.


Dear Peter,

Welcome to the fifth week of Current Issues in Organizational Behavior! To help you better evaluate and improve your discussion in this course, here is the profile of your discussion for week 4: Click here to download. Please answer the questions below after you read the profile.

What did you learn from the discussion profile? What will do you differently to improve your discussion next week?

Profiles from previous weeks:
Week 2 Discussion Profile
Week 3 Discussion Profile

Fig. 5 Example of weekly analytics report delivery (using a pseudonym)

Report Uptake and Student Response

In the initial roll-out 13 students were enrolled in this course. We observed a mixed pattern of student engagement with the report. On the one hand, students' average engagement with the report was disappointing. Despite delivering the report directly via email link, only seven of the thirteen students accessed it, and four of these accessed it only once. This aligns with prior findings that analytics are often seen as "nice-to-have" rather than "need-to-have" (Wise and Jung, 2019). On the other hand, three students accessed the report multiple times, and one actively contacted the instructor when experiencing difficulties gaining access. There is also evidence suggesting that students did make use of the analytic reports. In week 2, one student provided a thorough response to the reflective prompt in which they recognized their tendency to participate in the discussion forum later in the week, reflected on the reasons contributing to such behavior, and discussed how they were aiming to improve this in week 3.

Some concerns about the report were raised in the discussion forum. First, four students felt that the report metrics did not fully capture the quality of discussion participation and thus were not very useful. In part, this may have been due to the order of the information presented with the more straightforward quantitative information about participation shown first and the more nuanced information about thoughtful ideas shown at the end. Several students also described feeling anxious that they were not posting enough, even though they were actually very active discussion contributors. This raises the issue of problematic social comparisons documented previously (Wise et al., 2014). Additionally, there is some evidence suggesting a mismatch between the information that students wanted about their team discussion and the instructor's goals for the analytics. One student suggested that it would be helpful to include a weekly summary of the class's most salient points. While useful from a content perspective such information does not offer support for assessing and improving team interactions.

Summary

There is a critical need for team members to receive feedback about individual and group processes during their interactions to support team learning. The design and implementation of analytic feedback involve critical decisions about what metrics to provide, how to present them, and how to implement them in practices. This chapter provides four principles to guide the design of relevant, understandable, and actionable team learning analytics and describes a case of applying these principles to design team learning analytics in a specific context. In doing so, it documents the key decisions made at each step of the process to provide an exemplar of the analytics design process in action. Student response to the analytics raised important questions about how to avoid undesirable social comparisons that may evoke (unwarranted) anxiety.

For future research and design work in this area, considerations should be given to the intricate connections between the social, emotional, and conceptual aspects of team learning as well as how to appropriately frame the use of analytics related to measures of assessment and evaluation. Importantly, these considerations should be situated for the target student population regarding their dispositions (e.g., goal orientation), background knowledge (e.g., data literacy), and other relevant characteristics. Participatory design approaches are one promising approach that can be used to address the challenge of relevance described above by actively involving students as consequential agents in the design process (Buckingham Shum et al., 2019).

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Building Rapport and Trust in Collaborative, Team-Based Online Learning Communities

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Abstract This chapter explores three types of presence (i.e., teacher, social, and cognitive) that are essential in establishing communities of inquiry, the teacher's role in creating learning objectives, active learning experiences and appropriate online tools, the community of inquiry's social and cognitive aspects, the challenges teachers face in online learning environments, and how all of these ideas weave together to foster rapport and trust among learners.

Introduction

Successful online courses—those where learners say afterward that they were highly engaged and felt connected to their teacher, peers, and content—stem from quality course design. That sense of connectedness is commonly thought of as rapport and trust. For teachers, it is often a significant challenge to plan engaging asynchronous activities that eliminate boundaries, encourage teamwork and collaboration, and ultimately, foster rapport and trust in the learning community. This chapter explores three types of presence (i.e., teacher, social, and cognitive) that are essential in establishing such communities of inquiry, the teacher's role in creating learning objectives, active learning experiences and appropriate online tools, the community of inquiry's social and cognitive aspects, the challenges teachers face in online learning environments, and how all of these ideas weave together to foster rapport and trust among learners.

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Building Communities of Inquiry That Foster Rapport and Trust

Garrison (2017) defines e-learning as "the utilization of electronically mediated asynchronous and synchronous communication for the purpose of thinking and learning collaboratively" (p. 2). There is more to building rapport and trust in online learning than just providing opportunities for synchronous interactions. With intention, teachers must facilitate and provide opportunities for asynchronous interactions that encourage conversation, teamwork, and collaboration and do so in a way that fosters trust. Teachers can accomplish this goal by creating what Garrison et al. (1999) call a Community of Inquiry consisting of three types of presence: teaching, social, and cognitive.

Teaching Presence in Online Learning Environments

An effective and engaged teacher is critical to a learning community's success. Hattie (2003) asserts that a teacher's impact on learner success is greater than any other factors—class size, technology, instructional strategies, or others. He states, "It's what teachers know, do, and care about which is very powerful in this learning equation" (p. 2). Nye et al. (2004) attempted to quantify teachers' influence on student achievement. They studied teachers and students from 79 elementary schools across the state of Tennessee. Through random assignment, they controlled for gender, ethnicity, socioeconomic status, and class size. Their findings suggested that "the difference in achievement gains between having a 25th percentile teacher (a not so effective teacher) and a 75th percentile teacher (an effective teacher) is over one-third of a standard deviation (0.35) in reading and almost half a standard deviation (0.48) in mathematics" (p. 253). In short, the positive effect of a quality teacher on learner achievement is real.

The Role of the Teacher

But what does it mean for a teacher to be actively engaged? In recent years, it has become popular to use terms such as "facilitator," "coach," or "concierge" as a reference to teachers. The business world often uses "trainer" to describe the instructional leader. The use of these terms highlights the multiple tasks a teacher must engage in to facilitate a successful teaching and learning environment. Hattie and Zierer (2018) argue that these descriptors lead teachers to think that "standing alongside the learner" is enough when, in fact, the teacher must actively lead learners to "the edge of their understanding" (p. 152). The teacher must design and actively facilitate learning activities that lead to meaningful and long-term learning outcomes. Garrison (2017) refers to this as "monitoring and managing the transactional balance" of the learning environment. Simply put, it is not enough for teachers to merely facilitate and manage the coursework. They must take an active approach to engaging learners throughout the entire learning experience.

Backward Design: Beginning with the End in Mind

While all stakeholders play a pivotal role in developing a community of inquiry, the teacher's active presence—especially at the beginning of the course—sets the tone for the entire experience. A teacher's active engagement begins with planning learning outcomes and objectives that lead to specific interactions and learning activities. Before designing any interactions or learning activities, teachers must answer these questions:

- What do I want my learners to know and be able to do?
- What will success look like?

Wiggins and McTighe (2005) advise approaching course design by "beginning with the end in mind." In this backward design approach, teachers must identify the specific learning outcomes and determine what evidence will prove learners have achieved them. With the answers to these questions in mind, teachers create the learning objectives for the course. Then, once established, teachers can plan the learning experiences and interactions. Ralph Tyler (1949) wrote:

> Educational objectives become the criteria by which materials are selected, content is outlined, instructional procedures are developed and tests and examinations are prepared.
>
> … The purpose of a statement of objectives is to indicate the kinds of changes in the student to be brought about so that instructional activities can be planned and developed in a way likely to attain these objectives. (pp. 1, 45)

It is critical to clearly state the learning objectives early in the course and reinforce them through each learning experience and interaction. Learners must always understand not just "what" they are to do but "why" they are doing it. It is the "why" that hooks learners, increases their investment in the learning goals, and leads them to greater social and cognitive engagement.

Social Presence in Online Learning Communities

Social engagement begins with teachers inviting learners to establish connections and relationships with other learners. Social connections happen more organically in a traditional brick and mortar classroom than in online learning communities. Therefore, teachers must intentionally design activities that build the social aspect—or presence—within the learning community. Social presence has been defined as "the degree to which a person is perceived as 'real' in mediated communication" (Gunawardena and Zittle, 1997, p. 8). Weidlich et al. (2018) add "the subjective feeling of being with other salient social actors in a technologically mediated space"

(p. 2146). Perhaps Öztoka and Kehrwald (2017) describe it best as “the sense of ‘being there, together’ when ‘being there’ does not involve a physical presence” (p. 263). Tu and McIsaac (2002) researched social presence and interaction in online learning communities and concluded that there are three dimensions of social presence—social context, online communication, and interactivity—which positively influence online interactions.

Establish Social Context with “Social Spaces” and Weekly Announcement Videos

Establishing the social context starts with intentionally designed opportunities that encourage learners to get to know each other, share news and events, and celebrate each other’s success. These types of interactions are vital to establishing initial rapport and trust. Providing welcome sessions, weekly meetings, and “virtual watercoolers” can lead to increased participation and a greater sense of connectedness, ultimately leading to trust.

An illustration of a “virtual watercooler” is provided by Greyling and Wentzel (2007), who created a social space in their online course for 3000 learners. They created a forum for learners to have informal conversations unrelated to the more formalized course discussion forums. Learners were encouraged to share personal interest stories and celebrate accomplishments. At the end of the course, they found an increase in learners’ participation and engagement in discussions than that of previous courses. Learners reported having more positive feelings toward the content area and increased motivation for learning.

Another way to establish social presence is through weekly announcements and instructional videos. Typically posted by the teacher the first day of every week, these videos set the tone and expectations for the coming week. Whether teachers opt to be “on camera” or use slides to support the instructional details, learners must hear the teacher’s voice. By hearing the teacher’s voice, learners perceive the teacher to be a real person with whom they “can be at ease with” and establish a connection (Aragon, 2003, p. 59). The videos’ asynchronous nature allows learners to view them at their own pace. And, if created as a forum post, learners can ask questions and leave comments for the teacher’s consideration before a live class session.

There is evidence that asynchronous videos such as these promote social presence. Griffiths and Graham (2009) conducted a pilot study where pre-service teachers were required to watch asynchronous introductory and instructional videos. In these videos, the teacher was “on camera” to create a sense of connection. After viewing them, each learner recorded a video and emailed it to the teacher. The teacher responded in kind with a video offering encouragement and support. This type of exchange continued throughout the semester. In post-course surveys, students gave the online version of the course high ratings in every element of the university’s rating system and, in fact, higher ratings than any face-to-face offering of the same class.

Post-course evaluations specifically credit the videos for creating a sense of community. One student encapsulated the experience with this: "The instructor was one of the most caring and friendly teachers I've ever had" (p. 18).

In another study, a group of researchers studied the impact that video feedback had on learners' perceptions of their teachers' social presence. Most telling were the reflections from the teachers themselves. Teachers said they felt it was easier to convey emotions and excitement for the materials through video than merely through the written word (Borup et al., 2014).

Virtual "watercoolers" and asynchronous videos are just two examples of interactions teachers can use to establish social context and encourage online communication and interactivity. Learners perceive them to be engaging, fun, and ultimately, enable them to be "seen" as real people, which builds rapport and trust within the learning community.

Cognitive Presence in Online Learning Communities

Cognitive presence, the third aspect in a community of inquiry, is defined as "the extent to which learners are able to construct and confirm meaning through sustained reflection and discourse" (Garrison, 2017, p. 26). Activities and interactions that require learners to dialogue and collectively solve problems lead to teamwork and collaboration. Inherently, teamwork requires discussion and sustained reflection, which is the essence of cognitive presence. Activities must align with specific learning outcomes and require learners "stretch" their understanding of concepts and content.

Facilitating Online Communication: Discussion Boards

Tu and McIsaac (2002) cite online communication as one of three dimensions that foster the social aspect of an online community. Discussion boards (also known as forums) are often used to facilitate online communication. Teachers can pose questions, scenarios, or ask learners to reflect on readings or activities. In addition to developing social presence, these prompts enhance cognitive presence by inviting learners to engage in sustained communication with their peers. In a brick-and-mortar classroom, it is not unusual for one or two learners to dominate a discussion, and even if the teacher is highly adept in making sure all voices are heard, some learners prefer to think before expressing their thoughts aloud. Often learners will say that they feel left out of discussions or wish they had more time to reflect before sharing their thoughts. Online discussion forums alleviate these concerns. Because of their asynchronous nature, learners can think about and even research their responses before posting replies.

Forum prompts must closely tie to the learning objectives and encourage sustained communication and learners must perceive that the discussion is core and fundamental to learning. The teacher must set clear expectations for "quality" (substance, length, and writing conventions). But, in terms of the teacher's assessment of the discussion, Garrison (2017) warns that teachers should "not overly structure the discourse through excessive assessment and personal intervention" (p. 132). In doing so, learners may perceive that the teacher is in control, thus usurping their role as active members of the learning community and eroding the trust that might otherwise have grown through the online engagements.

Interactivity: Team-Based Projects

A third dimension of social presence as defined by Tu and McIsaac is interactivity.

Team-based projects are a type of interactivity, the heart of collaborative learning, and a mainstay of face-to-face instruction. In an online learning environment, it can be challenging to find the right "recipe" for incorporating projects when the core of instruction is conducted asynchronously, and learners are geographically dispersed and unable to meet in person.

However, the advent of free online conferencing tools has made it easier for groups to arrange virtual meetings that suit their work and life schedules. In a 2016 paper, Ekblaw explored the issues related to team-based projects. He asserts "that it is almost impossible to get a group of strangers to smoothly work together" (p. 124). Before assigning group work, he advocates for the use of informal discussion boards (i.e., watercoolers) that allow learners to get to know each other and find commonalities in shared experiences. The overarching goal is to establish rapport and trust among learners before requiring learners to work together for the first time. Groups that establish rapport and trust early on often work together effectively.

For the first project, teachers may opt to randomly assign learners to groups. The project should be "low-stakes" in terms of the overall course grade and instead focus on developing team roles and responsibilities. An example of a low-stakes project might be reading several articles about a course topic, synthesizing the key points, and then writing a reflection paper, creating a poster, or an interactive activity.

In subsequent projects, learners may choose to "self-select" groups. Over time, the teacher may opt to increase the stakes in terms of the overall impact on individual grades, but only after ensuring that all learners contribute to the project. Examples of high stakes projects are group research papers, recorded video demonstrations, and mock websites.

The teacher should survey students to find out what kinds of technology devices and tools they have available to them before creating projects that require tools that may not readily be available to all learners. Most importantly, the teacher must regularly check-in with the groups to ensure that each team member has a role aligned with the project's learning goals and outcomes and be ready to offer assistance if groups are struggling with the project goals or team roles.

Group projects can be effective tools for establishing rapport and trust among learners, but they can also do harm to the larger learning community if not managed effectively.

The Intersection of Teaching, Social, and Cognitive Presence

The foundational perspective behind the Community of Inquiry framework reflects a "collaborative constructivist" view of teaching and learning (Garrison, 2017, p. 9). In the Community of Inquiry model, it is important to consider how the circles, or types of presence, overlap. For example, social presence and cognitive presence support discourse. Learners must actively engage with other learners and with the content. Thus, it is important that the teacher facilitates cognitive presence through the careful and intentional selection and alignment of content and instructional interactions for a course while simultaneously ensuring that all learners are "seen" through consistent, diverse, and inclusive pedagogical activities that support social interaction. Teaching presence and social presence overlap to ensure that the climate is such that all learners feel welcome and safe. Teachers and learners share the responsibility of setting the climate by actively engaging with other learners and the goals for the course. Teaching presence and cognitive presence overlap to promote regulated learning, described by Garrison (2017) as "an awareness and ability to individually and collaboratively assume the responsibility to regulate the thinking and learning process" (p. 60). Garrison asserts that learners have a responsibility to be both teacher and learner and actively engage with community members in inquiry, the construction of meaning, and validation of understanding.

Consider a three-legged stool. If any leg is missing or uneven, the stool falls over. This visual explains why each type of presence is vital to the community. Imagine a scenario where the teacher opts for a facilitator's role instead of the active leader as previously described. As the facilitator, the teacher might perceive their role as checking on learner progress, assigning grades, and completion status. Learners are on their own to navigate the course content with minimal direction and clarification. It is difficult to establish rapport and trust among learners when they perceive the teacher to be merely a facilitator. When confusion or conflict arises, they are unsure of where to turn. Garrison writes, "[Collaborative thinking and learning] is the means to deep understanding and shared metacognitive awareness for the collaborative inquiry approach that makes possible continuous learning" (pp. 130–131). Moreover, both the teacher and learners are responsible for and must actively engage in each aspect of presence for the community to be successful.

Defining Engagement and Active Learning

Engagement and active learning: These two terms are widely discussed yet often seen as elusive goals in communities of learning. Fredricks et al. (2004) surveyed the research on what aspects of engagement led to increased academic motivation and achievement from behavioral, emotional, and cognitive perspectives, and espoused that all three must be present to fully engage learners in learning. Behavioral engagement means ensuring that learners are actively participating in both academic and social interactions. Discussion forums and virtual watercoolers are opportunities for active engagement. Emotional engagement refers to the connection learners have to other learners, their teachers, and academic content. Positive emotional engagement can influence learners' willingness to complete assignments. Further, cognitive engagement ties to investment and the learner's willingness to persevere when ideas, concepts, and skills are new and complex.

Berry (2020) suggests that engagement is more of a continuum than an individual state of being. After interviewing teachers about their perceptions, she developed a model depicting three forms of engagement and three forms of disengagement. Learners could be actively disengaged and disruptive on one end of a continuum or actively engaged and driving their own learning on the other end. In essence, it is more than just "doing" or "participating" that defines engagement. Investing in and driving one's own learning is the ultimate form of active learning.

In terms of active learning, Himmele and Himmele (2017) contend that it is not enough for learners to simply participate. They advocate for Total Participation Techniques (TPT), which are "teaching techniques that allow for all learners to demonstrate, at the same time, active participation and cognitive engagement in the topic being studied" (p. 4). They developed a TPT Cognitive Engagement Model based on the idea that real learning occurs not only when every learner participates but also when it is tied to higher order thinking strategies. An activity where everyone participates may not necessarily lead to long-term learning. Real learning occurs when the interaction is linked to strategies that lead to higher levels of cognition. To accomplish this, Barkley and Major (2020) suggest using graphic organizers and developing partner activities to activate prior knowledge and then helping learners transfer what they already know to new ideas and concepts. Sousa (2006) recommends chunking information into 10- to 20-minute segments to alleviate "mental fatigue or boredom and attention drifts" (pp. 45–47). Active learning techniques such as these help learners develop confidence. That confidence fosters rapport and trust among learners.

Linking Engagement and Active Learning to Tools

In the e-learning environment, there are a plethora of online tools that teachers can use to engage learners in active learning activities. But often, teachers will design learning activities with a particular tool or software in mind. Fisher et al. (2021) suggest that teachers should focus first on the type of engagement (or interaction) they want for their learners before choosing a tool to support or facilitate the activity. They suggest focusing on what learners need to accomplish in their learning.

- *Find information* efficiently and be able to evaluate whether the information is useful, credible, accurate, and corroborated by other sources.

- *Use information* accurately and ethically.
- *Create information* such that its creation deepens one's understanding.
- *Share information* responsibly with audiences for a variety of purposes (Frey et al., 2013, p.1).

There are a myriad of free online conferencing tools that facilitate virtual collaboration and tools such as YouTube, Padlet, and Kahoot make the sharing of information easy. When used effectively, these tools can enhance virtual interactions and build rapport and trust among group members.

Confronting Challenges

In 1989, Moore predicted that, in the years ahead, learner–learner interaction would challenge thinking and practice. He lamented that classrooms were organized to meet the needs of the institution or school and not the learner because "it is the cheapest way of delivering the teaching acts of stimulation, presentation, application evaluations, and learner support" (p. 2).

In 2008, Christensen, Horn, and Johnson foresaw the disruptive impact computers could have on instruction and learning. They boldly predicted:

- By 2018 "online, learner-centric learning will account for 50 percent of the 'seat miles' in U.S. secondary schools."
- By 2024, "about 80 percent of courses will be have been taught online in a learner-centric way" (Christensen, et al., 2011, p. 102).

In 2015, *Blended: Using Disruptive Innovation to Improve Schools* followed with this statement on the author's website: "If online learning has not already rocked your local school, it will soon!" Little did Horn's marketing department know how prophetic that statement would be. Horn outlined models for blending brick-and-mortar with online learning such as station rotation, lab rotation, flipped classrooms, and flex and hybrid models of instruction. He wrote: "the most successful programs avoid the trap of technology for technology's sake by beginning with a clearly articulated problem or goal that does not reference technology" (Horn & Stacker, 2015, p. 98).

Conclusion

Teaching and learning environments are rapidly evolving. Additionally, tools to support teaching and collaborative learning in diverse settings are continually improving. Teachers must become adaptive and flexible in addressing the myriad of issues associated with these emerging environments and tools. Garrison (2017) says, "E-learning has the ability to eliminate boundaries and bring educational participants together in communities of inquiry" (p. 171). In doing so, teachers need to stay focused on the overarching goal of creating learner-centered communities of inquiry that foster rapport and trust where learners can thrive individually and collaboratively.

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Mediated Interactions via WhatsApp: a Social Space for Teacher Development in Brazil

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Abstract Drawing on the seven "new learning" affordances in Cope and Kalantzis (*E-learning ecologies: Principles for new learning and assessment*, Routledge, pp. 1–45, 2017), an agenda for integrating digital technologies in the classroom, this chapter presents teacher education initiatives via WhatsApp, part of *Taba Móvel*, a Brazilian project which seeks to discuss the use of digital mobile technologies in teaching and learning. One of the benefits for integrating WhatsApp into any classroom is using a technology-enabled collaborative tool to increase learning opportunities in many different curricular areas.

Cope and Kalantzis's (2017) proposition is that "everything might change in education with the application of educational technologies. But also, in a pedagogical sense, nothing might change. Technologies are pedagogically neutral" (p. 6). The authors agree with Cope and Kalantzis's (2017) thoughts regarding the need to choose a given technology based on the pedagogical goals of a task and daresay that the development or the augmentation of digital technologies can also generate pedagogical possibilities and insights only made possible due to the features and possibilities of these technologies. Such is the case with WhatsApp, an application that was not originally created for educational purposes, but whose features, especially mobility and ubiquity, enable teachers to participate in educational initiatives from anywhere and without a fixed schedule.

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According to its official website,[1] WhatsApp is a free application available for download on Android and iOS operating systems that aims to optimize communication between people. Currently, this application has over two billion users in more than 180 countries and its features include the ability to create, share, and exchange text messages, audios, videos, location, voice, and video calls, among others. The features of WhatsApp, which facilitate instant communication and multimodal material production, as well as the application's high popularity for social networking in Brazil, determined the choice for WhatsApp for teacher development initiatives created by the second and third authors of this chapter. These initiatives stemmed from an extension and research project from the School of Letters of the Federal University of Minas Gerais, Brazil, titled *Taba Móvel* (Mobile Taba). Their aim was to promote opportunities for active collaborative learning processes regarding the understanding and use of mobile applications and games in language teaching and learning. The word *Taba*, in Portuguese, harks back to Brazil's indigenous villages and reflects the concept underpinning these initiatives. This native Brazilian dwelling is a circular space in which the villagers exchange experiences. Thus, a *Taba* is a space inhabited by all the individuals of a community, who share their lives, their knowledge, and their practices. In this chapter, we present the initiatives developed by the *Taba Móvel* and discuss them in consideration of the seven "new learning" affordances in Cope and Kalantzis (2017), an agenda initially established for integrating digital technologies in the classroom but that can also be used in the preparation of future teachers as well as professional development of in-service teachers.

Background

Teacher development initiatives via WhatsApp will be presented in consideration of the seven "new learning" affordances espoused by Cope and Kalantzis (2017). The authors use the term affordance "to describe what's possible with technology"[2] and to discuss what they refer to as the seven "new learning" affordances based on reflexive pedagogy, which they juxtapose with didactic pedagogy to pinpoint the differences between these perspectives. The key features of Cope and Kalantzis's (2017, p. 9) didactic pedagogy include: a) direct instructional guidance since the "balance of control of a learning environment must be with the instructor"; b) a strong "focus on cognition" and long-term memory; c) a focus on the "individual learner" because long-term memory is singularly individual; and d) the fact that the learner can "demonstrate that they can replicate disciplinary knowledge" by remembering facts and appropriately applying definitions. Educational practitioners

[1] https://www.whatsapp.com/about/

[2] https://www.coursera.org/lecture/elearning/whats-the-use-of-technology-in-learning-introducing-seven-e-affordances-VKPF5

and thinkers have offered systematic critiques and practical alternatives to didactic pedagogy, which Cope and Kalantzis (2017) referred to as reflexive "in the sense that they represent in certain senses a revival of the dialogical, where the agency of the learner is at play in a dialectic between teacher and learner, the to-be-learned and the learning" (p. 9).

Reflexive Pedagogy

Cope and Kalantzis (2017) present a gloss of what they call reflexive pedagogy. In the authors' terms, the construct can be briefly summarized in four major points:

1. The connection between the instructor and learner changes toward a more synergistic and interactive relationship. The actual learning behaviors are considered more of a collaborative reciprocal multiple directional approach with a two-way interaction between the agents (instructor/students, students/students). The learner takes a different position and has more responsibility interacting in a unique transactional framework of learning. Adding to the learning, the content may create deeper connections among students, instructors, and ideas. What is unique in this type of learning is that the development of the content is created from multiple types of sources, which can be beyond printed forms, like the Internet, coming from experiences, real-life stories, or authentic occurrences.
2. In today's world most individuals depend on just-in-time information. Since we all have the Internet and mobile devices at our fingertips to look up facts and information, this consideration has led to many researchers stating that long-term memory is not as important as it used to be. Cope and Kalantzis's (2017) research supported that learning "involves a shift in emphasis from cognition to epistemic artifacts" (p. 11).
3. Knowledge is not only a matter of what one knows as an individual, but rather the ability to identify the social sources of the knowable, work with peers to collaboratively create a shared repertoire, discern critically what is relevant, and synthesize and analyze information to form decisions and opinion, etc.
4. Knowledge is always dynamic and evolving and can provide the learner a deeper meaning in multiple situations and environments. In a reflexive pedagogy, well-established facts, definitions, and theories are used to contextualize arguments and give support to the construction of new knowledge.

   With these points in mind, Cope and Kalantzis (2017) propose that reflexive pedagogy, enabled by educational technologies, may create "e-learning ecologies." The authors use this metaphor because they consider a learning environment an ecosystem, consisting of the complex interaction of human, textual, discursive, and spatial dynamics.

E-Learning Ecologies and the Seven Affordances

According to Cope and Kalantzis (2017), although the principles of reflexive pedagogy are not new, they become feasible with educational technologies. In this regard, digital technologies can provide support to a major change in ecologies of learning, leading to a change of pedagogical paradigm, which means a shift from didactic to reflexive pedagogy. Based on this conceptual framework, the authors set an agenda to contemplate this possible change by using digital technologies to create e-learning ecologies based on the seven new learning affordances.

The seven learning affordances are: ubiquitous learning, active knowledge production, multimodal knowledge representations, recursive feedback, collaborative intelligence, metacognitive reflection, and differentiated learning. These affordances will be further discussed as they evolved in the teacher development initiative via WhatsApp featured in this chapter.

The Teacher Development Initiatives Via WhatsApp: *Taba Móvel*

Taba Móvel seeks to offer opportunities for the development of digital literacy, especially for K-12 teachers, and to discuss the use of digital mobile technologies in teaching and learning, especially languages. The project was conceived as a large technological village, a collective and collaborative place for exchanging ideas and skills related to new media. *Taba Móvel,* therefore, arises from teachers' demand for learning how to deal with mobile technologies in their classrooms. The courses stemming from the project entail three phases: (1) familiarization with different mobile applications and recognition of the genres that circulate on mobile platforms, (2) methodological discussions about the potential of these resources—in this phase, participants are invited to reflect on the possibilities and limitations of mobile platforms and applications in language teaching and learning, and (3) integration of mobile devices in language teaching practices, when teachers are also invited to reflect on the use of mobile devices based on classroom experiences and share these experiences with colleagues. The project currently has three major teacher development initiatives: (a) using mobile technologies for teaching English as an additional language, (b) using mobile technologies for teaching Portuguese as language arts, and (c) using games for teaching languages. Table 1 displays the general information regarding these initiatives.

All initiatives counted on a group called *Taba Móvel Admin,* created on WhatsApp, in which teachers and undergraduate/graduate TAs interacted to solve possible problems during the courses. The interaction in the courses took place through text messages and audio messages. In addition, participants sent photos, shared locations, and utilized a variety of other WhatsApp functionalities. All activities were developed considering the most frequent pop culture genres for this type

Table 1 Taba Móvel general information

	Editions	Number of participants	Number of mediators	Length
Using mobile technologies for teaching English as an additional language	Mobile Taba 2015—Pilot	20 participants in a single group	4 educators 4 TAs	6 weeks
	Mobile Taba 2016	67 participants in two groups	4 educators 8 TAs	8 weeks
	Mobile Taba 2019	227 participants in six groups	6 educators 12 TAs	8 weeks
Using mobile technologies for teaching Portuguese as language arts	Mobile Taba 2017—Portuguese	94 participants in two groups	4 educators 6 TAs	7 weeks
Using games for teaching languages	Mobile Taba 2017—Games	321 participants in five groups	5 educators 10 TAs	8 weeks

Note: Original unpublished table created by the authors for this manuscript

of application, such as selfies, memes, photo collages, location maps, and more. The proposed tasks and productions carried out throughout the courses will be detailed and discussed in the next section from the perspective of the seven affordances of Cope and Kalantzis (2017).

Relating the New Learning Affordances to Taba Móvel Initiatives

In this section, we briefly present the new learning affordances, relating them to different elements of the teacher development offered by *Taba Móvel*, and discuss some of the lessons learned from these initiatives.

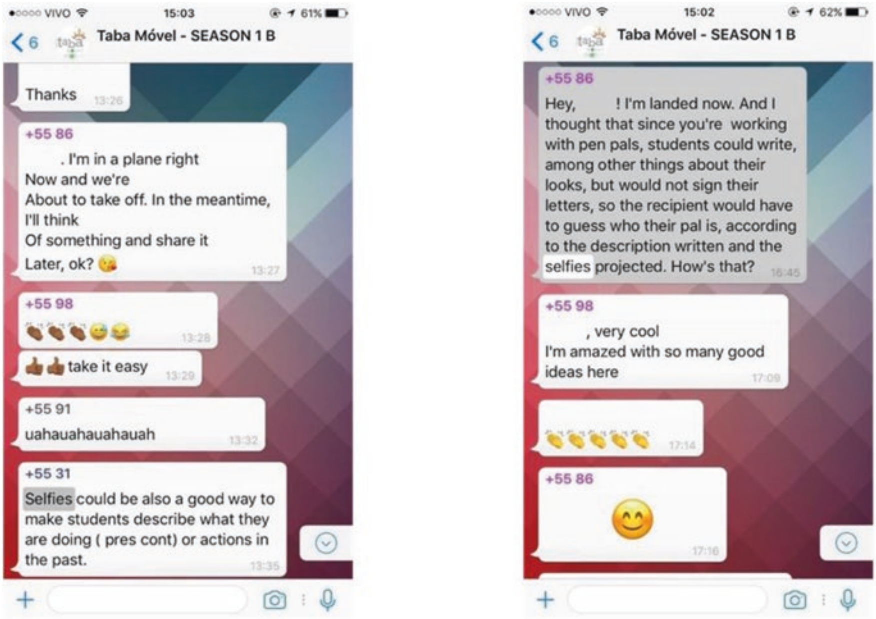
Affordance #1: Ubiquitous Learning

The knowable world outside was traditionally brought to the classroom via media in a one-to-many perspective at predetermined times and physical spaces, and with dynamics in which the learner interacts minimally, or in a limited way. As the media in society changes, so does the media in classrooms. In Cope and Kalantzis's words (2017), "[w]here the mass media were one-to-many, the social media are many-to-many" (p. 15). Whereas "the mass media configured audiences, viewers and readers as relatively passive recipients, the social media configure 'users' simultaneously as readers and writers, viewers and image makers, media creators and media consumers" (p. 15). Likewise, whereas the mass media presupposed a fundamentally similar audience (because their message had to be mass produced and mass distributed), "the social media express and reflect a variety of identities and interests depending on a user-selected pattern of friends, or likes, or followings" (p. 15).

Underlying these transformations and playing a crucial role in them are technological innovations, especially ubiquitous computing. Braga et al. (2017a), drawing on Saccol et al. (2011), and Yahya et al. (2010), remind us that ubiquity occurs from the use of mobile information and communication technologies as well as sensors and location mechanisms that, convergently with various media, allow the users to access technological resources from wherever they are, and, consequently, form networks.Through the affordances of mobile devices, ubiquity manifests itself in such a way that the information is present unless the learner intentionally removes it (permanency), available whenever necessary (accessibility), and immediately searchable by the learner (immediacy). It is also manifested as various types of media can be used to facilitate interaction among students, teachers, and specialists (interactivity) and as the environments are sensitive to the learners' real needs or situations and can adapt to them (context awareness).

These ubiquitous mechanisms in mobile technologies, especially in the WhatsApp application, were considered for choosing the type of technology for teacher development courses. The offer of courses via mobile digital technology allows teachers to interact anywhere and anytime, in addition to affording opportunities for teachers to experience the potentials and limitations of WhatsApp from a learning-by-doing perspective. Moreover, ubiquitous learning was a key element in these courses, allowing Brazilian teachers to interact from the cities in which they lived—in Brazil or abroad, as well as from home, during break time at school, or other times and locations, without having to deal with a fixed schedule. In the following examples, sections of a sequence of interactions about one of the courses discussed in Braga and Martins (2019) demonstrate how one of the course participants interacts with her peers while waiting for her plane to take off and resumes her conversation with the group when the plane arrives at its destination. As the WhatsApp messages remain in the application, unless purposely removed, the course participants had no difficulty retrieving the interactions in the group as can be seen in Fig. 1.

Braga and Martins (2019) claim that "one's relationship with information obtained or provided via mobile devices changes considerably depending on how readily available the device is and on the features that allow 'just in time' and 'on demand' interactions without necessarily having to put other activities on hold" (p. 370). The authors add that "being able to read interactions from an airplane seat using a smartphone is not as cumbersome as retrieving a laptop from a carry-on bag or having to wait to access a desktop computer" (p. 370). The affordances of ubiquitous technologies allowed the course tutors to interact with the Taba Admin—anytime and anywhere—to solve problems when needed, such as to insert participants back into a group when they accidentally left the group, discuss the course of action when there was any kind of misconduct regarding agreed-upon rules, such as sharing political and religious posts, interact on weekends or late at night, or in the event of additional issues regarding the course management.



Note: Braga & Martins (2019, p. 370).

Fig. 1 Examples of interactions focusing on "just in time" and "on demand" communication from a plane. Note: Braga and Martins (2019, p. 370)

In addition, the ubiquitous technology, coupled with the reflexive pedagogy in Cope and Kalantzis (2017), allowed for instant responses, making it possible for everyone to interact during the tasks in a decentralized manner. This communication and learning was fostered by the ability of anyone in the group to be the initiator and share their thoughts based on their practices.

Affordance #2: Active Knowledge Making

Cope and Kalantzis (2017) claim that creating active knowledge is key to the pedagogical process. In other words, learners should be allowed more scope for agency in their learning, despite having some kind of framework, creating what these scholars refer to as "generative restraint." Cope and Kalantzis suggest a balance between openness and structure so that learners are responsible for their learning processes while receiving the necessary scaffolding to maintain the focus. The learner can navigate in the external world by means of digital technology and produce their own knowledge. In the case of *Taba Móvel*, teachers had the opportunity to produce texts and create materials with digital tools through activities that, on the one hand, promoted the protagonism of the participants in the production of knowledge, while offering support to recognize, analyze, and reframe the established knowledge. In one of the tasks, which consisted of making a creative meme, the teachers had opportunities to produce a multimodal text, and the freedom to choose the most suitable meme maker tool from the many available online. The task also afforded opportunities for teachers to exercise their agency as they were asked about the characteristics of creative memes and how to use them pedagogically, leading them to reflect on shared knowledge—features of memes—and collectively build something new—characteristics of creative memes and their pedagogical use—through a planned sequence of activities. The last activity, a wrap up, was done to raise awareness of the process since the objective of the training was to offer insights on how to integrate memes in the classroom.

Underpinning the wrap up activity is the idea that teachers would have the opportunity to learn by doing and replicate or adapt the same task to their own classrooms. In this sense, they were agents of their own knowledge-building process while they were involved in a sequence of activities purposely structured to favor the achievement of the task's objectives. The initiative regarding the use of games for teaching and learning languages follows the same strategies used in the courses on using mobile technologies for teaching English as an additional language.

Figure 2 displays an activity that illustrates the "balance of openness and structure" suggested by Cope and Kalantzis (2017, p. 21).

The course on games proposed missions to be accomplished, which unfolded into a number of activities that favored both freedom and restraint. The course design promoted opportunities for the course participants to become knowledge producers as they had to not only research features of different game genres but also share their thoughts on how to use them pedagogically.

Note: Images created by the course designers, proponents of Taba Móvel.

Fig. 2 Stage introduction and task instruction

Affordance #3: Multimodal Meaning

Contemporary digital media combine multimodal genres (e.g., text, image, sound) made public via the Internet. If the analogue era saw information being disseminated through letters, cinema, radio, telephones, etc., the digital era facilitates the distribution of information through multimodal digital texts (Cope and Kalantzis, 2017). The tasks proposed in the teacher development courses involved multimodal knowledge representations, for both the reception and the production of multimodal genres that circulate on social media. Figure 2 brings an example of activities that required the participants to watch a video. The very posts developed by Taba Móvel's team to facilitate the tasks were multimodal themselves as they organized information in a bite-sized manner as suggested by Pegrum (2014), and in a format that perfectly fit the practices mediated by mobile applications and devices.

In another task, on the other hand, participants are asked to create a meme, an explicitly multimodal text. Even the interactions on WhatsApp use different media. Figure 2 shows a task in which the course participants were requested to record oral messages and report opinions and findings in writing. In addition to memes, teachers produced cyber poems, reviews, and collages among other multimodal digital genres.

Affordance #4: Recursive Feedback

According to Cope and Kalantzis (2017), the role of recursive feedback is to provide enough support to constructively contribute to the development of the proposed tasks. As Smith et al. (2017) state, as learners participate in a class and engage with one another in the intentionally designed e-learning environments, they can receive feedback on content, form, tool, pace of production, social norms of the learning community, and other aspects of their learning. One task that demanded repeated feedback from both the educators and the TAs required teachers to use WhatsApp's location function to write a review on any place they visited, but many of them needed extra support, mainly on the features of this textual genre.

The following excerpts illustrate the different feedback provided to ensure teachers could write their own reviews:

Educator: guys, in real life we do not write reviews of our homes, but of places we've been and impressed us in a sense. A bar, a bakery, a restaurant, a supermarket etc. A review has a critical tone. So, an actual review highlights good aspects and criticizes negative ones; encouraging or discouraging people to go there (Reviews are full of adjectives).

TA: Is there any interesting spot near the driving school? How about writing a review about it?

TA: Writing a review

Reviews are a staple of journalism. Almost anything can be reviewed: music concerts, films, video games, products, books or restaurants.
The aim is to offer an honest critique of the object under review, and to make a recommendation to your audience.
TA: share your opinions on a review, what do you think?;)
TA: Your role as a reviewer is to inform
describe analyze adviseMake sure you follow these four moves
It's great to see your comments on your peers' reviews.
Make sure you write an informative one so that your peers feel like commenting.
TA: Nice review! It must have a stunning view.

The recursive feedback constructively contributed to the development of the tasks by the course participants as they revised their productions and submitted new versions in the group for teachers' and peers' appreciation. It is worth mentioning that, at times, the feedback was given by the peers who aimed to contribute to the best version of the texts. Many times, the recursive feedback was used to remind participants of the pace of production as tasks were to be posted weekly. In addition, the high number of messages exchanged also demanded the TA's instant interactions regarding reposting instructions and tasks. Feedback from participants regarding the course design and mediation was taken into consideration in the planning of future editions.

Affordance #5: Collaborative Intelligence

In defending the idea of a collaborative cognition as central to the construction of knowledge, Cope and Kalantzis (2017) assert that "[i]n e-learning ecologies, it becomes more necessary to recognize the social sources of intelligence" (p. 33). According to the authors, there is a need for "a shift away from knowledge memorization towards a culture of knowledge sourcing; and developing skills and strategies for knowledge collaboration and social learning" (p. 33). One of the most important aspects of collaborative intelligence is to design learning opportunities around peer collaborations.

It is the authors' understanding that mobile technologies provide a prolific way of doing just that. We agree with Cope and Kalantzis (2017) that "[t]oday, we have remarkable, world-connected cognitive prostheses at our fingertips, carrying them in our bags or keeping in our pockets" (p. 34). Along these lines, Braga et al. (2017b), based on Royle et al. (2014) and Traxler's (2009), argue that the use of mobile devices leads to changes in the way mobile users produce knowledge. In Traxler's (2009) terms, these technologies have a transforming effect on the very nature of cultural artifacts and work relationships, significantly altering the way people experience language, their identities, and their social practices.

The design of the courses offered by *Taba Móvel* was created with a vision to promote opportunities for collaboration through the use of WhatsApp's application features. Course participants interacted through written and oral messages and made use of the reply feature to answer specific questions from messages sent by the teachers and the peers. In addition, these participants used the share feature of the application to post resources related to the group as well as materials they have used in their classes. The tasks in the courses involved having participants rely on game descriptions available online, as well as on the literature about games and learning, not only to analyze a sample serious game, but also to read their peers' analyses and build on their interpretations. One of the strategies of the course was to promote opportunities for the teachers to create their pedagogical material to use in their classes. These materials were usually revised after peers' and teachers' feedback. The created repertoire can be considered an outcome of shared intelligence since it was built collaboratively and adapted to the participants' classroom practices, based on their situated contexts.

Affordance #6: Metacognition

Cope and Kalantzis (2017) argue that metacognition is thinking about one's own thinking and its awareness may improve one's performance. Metacognition "also involves theoretical work where the learner not only immerses themselves in content, the facts of a topic, but is able to relate these facts to overall explanatory frameworks, applying facts to frameworks and testing frameworks against facts" (p. 35). This process was taken into account in the course's design as participants were usually asked to reflect upon what they were doing and wrap up the activities in a way that they were aware of the rationale behind the tasks.

Affordance #7: Differentiated Learning

As for differentiated learning, Cope and Kalantzis (2017) argue that new educational media allow for much more flexibility as learners do not necessarily have to do, or even to learn, the same thing at a given time, following the teacher's steps one by one. This flexibility that favors respect to learners' individuality—choosing tasks, creating content, and deciding when to do the task—may facilitate learners' engagement with the course. Teachers and disciplines scaffold learners' (re)creation of the world as they become knowledge producers and function as disciplinary practitioners themselves, designing their own unique process. That does not mean learners would work alone; rather, as stated by the authors, complex structured social interactions can occur in technology-mediated learning environments designed on social media principles. In this light, the notion of equality is replaced by that of equity in which learners “can be doing different things but of comparable cognitive or practical difficulty” (p. 38).

The teacher development courses promoted opportunities for the course participants to design their own process. Learners were assigned a task like watching a cyber-poem and then were required to produce one of their own. In the follow-up activity to this task, participants were asked to watch each other’s video poems and give feedback. They were supposed to use WhatsApp’s Reply function to express their feelings about their colleagues’ productions by means of emojis. Learners worked as a team in revising the content of the video cyber-poem.

One of the aims of the course was for teachers to produce materials they could easily adapt to their own classes. With that in mind, the design of the course offered some steps to help course participants to (re)create what they considered to be adequate to their situated contexts. Although the tasks were created for a given setting (age, language level, etc.), the feedback received by the peers and tutors contributed to the final edition of the material. The possibility of creating materials on the palm of their hands and receiving immediate feedback from the group, allowed enough flexibility and brought to the forefront of the process the role of digital technologies as mediators of the learning process.

Implications to Other Areas

Although in this chapter the seven affordances by Cope and Kalantzis (2017) were related to course designs offered in the context of language, they seem to be an alternative for teacher development initiatives in all areas, especially the areas of STEM. As suggested by the authors, the seven affordances can be used as an agenda for teachers willing to shift from a didactic to a reflexive paradigm that views educational technology as an agent of e-learning ecologies, an ecosystem consisting of the complex interaction of human, textual, discursive, and spatial dynamics.

One of the true benefits for integrating a tool like WhatsApp into any classroom is using a technology-enabled collaborative tool to increase comprehensive learning in many different curricular areas. Furthermore, many researchers have stated that using collaborative learning techniques to solve complex problems further opens opportunities in teaching in the areas of STEM. By combining subject-specific curricular goals with collaborative tools, educators can incorporate the features of ubiquitous learning in the task design within the areas of STEM, making learning more flexible in terms of time and space. Other opportunities may arise as educators integrate multimodal knowledge representations to interpret data and create graphs and charts to express complex issues meaningfully to students. Recursive feedback could also inform STEM design tasks to emphasize the development process without losing sight of the product.

Creating subject-specific lessons under the perspective of the seven affordances and integrating the techno collaborative tools can benefit all curricular areas.

Conclusion

The WhatsApp-supported teacher development experiences reveal that the mobility of smartphones has enabled language teachers from across Brazil to discuss the use of mobile devices and applications with their peers and create materials based on their situated contexts. In addition, the ubiquity and mobility of the devices facilitated the participation of these teachers, who were able to choose when and where to interact with their peers. Despite the potential of the tool, at times the very features that favored collaboration and the creation of a shared repertoire caused an accumulation of messages that hindered the participants' reading and navigation during the course, demanding attention from the teachers so that they could keep track of the proposed tasks. Further, the high flow of messages, especially in the initial phase of the courses, required greater participation of the team of teachers and teacher assistants (TAs).

Other findings reflected that some participants struggled with a learning curve associated with learning not only how to use WhatsApp but also how to use their smartphones. The large number of messages made a few participants uncomfortable with the constant notifications and the loss of posts already made. This concern required a training intervention to show how to mute the group and use the search function available in the application. Another occurrence was that several participants left the course in the first weeks without giving any explanation. It was necessary to mobilize the pedagogical team to contact these participants to understand what was happening and to offer help. We found that many reasons were associated with exiting the WhatsApp groups, such as lack of memory space and leaving the group by mistake. Closely monitoring the participants and showing interest in their participation led to regaining most of these participants.

As the application was not originally created for educational purposes, there is no feature that can differentiate course participants from the team of mediators. To minimize this problem and offer course participants the possibility to identify teachers and TAs more easily, the course design of the last edition included the use of the cell phone emoji—📱—to identify the pedagogical team.

The use of multimodal posts with images and written text for assignments facilitated communication in the groups, considering not only the simple and practical nature of those posts but also their suitability to WhatsApp. As Pegrum (2014) states, the essence of mobile learning is about when (now), who, what, and why, combined with brevity, and balancing too much and too little information. However, it is worth pointing out that since these posts do not allow hyperlinks, the pedagogical team had to be careful to include links to external tools, whether for accessing some type of input or experimenting with internet tools.

Based on the relationships between the teacher development course design and the seven "new learning" affordances described in this chapter, as discussed in Cope and Kalantzis (2017), one can affirm that these affordances are aligned with teaching and learning perspectives that contemplate interaction, collaboration, and the construction of a shared repertoire. These affordances seem well suited for either pre-service or in-service teacher education initiatives.

Moreover, the seven "new learning" affordances can be seen as an alternative for mobile-learning educational experiences in that they take account of the mobile and ubiquitous nature of the devices, multimodal representations, and possibilities of collaboration.

The educational experiences carried out via mobile application seem to indicate that digital technologies mediate the process of learning and provide support for the achievement of pedagogical goals. These educational experiences via WhatsApp show that mobile technologies could play a role as an agent in learning ecologies since their nature (mobility, ubiquitous) and features (audio recording, replying, searching) may promote new methodological insights that can generate innovative educational experiences as well as promote opportunities for teachers to re-signify their practices.

The *Taba Móvel* teacher-education initiative created emphasis on empowering teachers by teaching innovative strategies for using WhatsApp and finding other affordances and approaches to learn how to integrate those collaborative strategies into their own classroom instruction. As technologies can be pedagogically neutral, mobile applications such as WhatsApp could well be used for teacher development initiatives in areas like STEM due to its many unique possibilities for learning.

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Social Presence in Technology-Enabled Team Learning Environments

Caroline Kairu

Abstract Social presence has been identified as one of the key factors in influencing motivation in learning. Social presence helps in increasing interactivity which fosters genuine learning and development of a community of inquiry, development of higher levels of critical thinking, reflection, and problem-solving. An analysis of social presence and lack of social presence emphasizes the need for educators to evaluate the degree of social presence in the online learning environment. Technology affords ways for teams to build interaction within the team and with the instructor. Suggestions for best and promising practices in evaluating social presence in online technology-mediated team learning and methods for increasing social presence are discussed.

Introduction

Social presence can be viewed as student-to-student and student-to-instructor interaction that builds trust and personal connections. In this chapter, social presence is explored from various perspectives with the encouragement of instructors and students to build social presence as a means of fostering optimal team collaborations. Social presence was originally defined in 1976, by social psychologists Short, Williams, and Christie, as the degree of prominence in a conversation by one person during an interpersonal relationship (Biocca et al., 2003). The concept included the quality of the medium of communication, the level of intimacy displayed through expression and emotion, and the technology used to mediate the communication. Since then, definitions and interpretations of the definition of social presence have been continuously revisited by researchers and practitioners. Gunawardena and Zittle (1997) defined social presence as the degree to which a person is perceived as "real" in computer-mediated communication (Kear et al., 2014) and hypothesized that people seek to maintain equilibrium in their interactions (Swan and Shih, 2005). Rourke et al. (1999) expanded on the definition by identifying three elements that

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help define social presence: cohesiveness, affect, and interaction. Tu (2002) further classified social presence into online communication, interactivity, and social context dimensions, and Biocca et al. (2003) defined social presence as the “sense of being with another.” Effective social presence has been characterized when one is aware of the ability to access the interactions, interpersonal aspects, and intelligence of others, and has a feeling of connectedness and psychological presence between the communicators (Oh et al., 2018).

Swan and Shih (2005) defined social presence as “the degree to which participants in computer-mediated communication feel effectively connected to one another” (p. 115). Other definitions include “an individual’s ability to demonstrate his/her state of being in a virtual environment and so signaling his/her availability for interpersonal transactions” and “the ability of participants to identify with the community, communicate purposefully in a trusting environment and develop interpersonal relationships by way of projecting their individual personalities” (Whiteside et al., 2017, p. 12). Quality interaction is evident when: (a) there is a significant contribution to discussions in a team or collaborative activity, (b) students clearly respond to both peer and instructor prompts and requests, and (c) students appreciate other students’ ideas and healthy criticism, and displays of critical thinking. Positive student interactions in technology-enabled team learning environments can further increase student interaction, leading students to take ownership of their learning (Fahy, 2003). Social presence can be with both instructor and peers. The instructor does not always have to be the primary source of student learning support, as peer-to-peer support influences student accountability overall to team performance.

Social interaction may increase student satisfaction in the quality of the course content. However, there are a number of factors that may affect effective use of social presence and student satisfaction, such as: (a) group size in both team and online group discussions (Akcaoglu and Lee, 2016), (b) the level of knowledge in the use of assigned social and online educational platforms, (c) online privacy concerns (Tu, 2002), (d) netiquette, and (e) self-efficacy (Zhan and Mei, 2013). For groups and team interactions to be effective, there is a need for simplicity in the exchanges of information in digital and computer-mediated communication, and the group members must be able to communicate effectively and clearly for increased collaboration (Lowry et al., 2006).

Community of Inquiry Framework

The *Community of Inquiry* (CoI) framework, developed by Garrison et al. (2001), described a dynamic model of social presence for the pursuit of meaningful inquiry in learning. The CoI framework views cognitive presence, teaching presence, and social presence having integral relationships (see Table 1). Cognitive presence is defined as the ability to devise meaning through construction, exploration, resolution, and confirmation of understanding through communication (Garrison, 2007).

Table 1 Examples of social, cognitive, and teaching presence

Elements	Categories	Indicators
Social presence	Effective expression Open communication Group cohesion	Emoticons Risk-free expression Encourage collaboration
Cognitive presence	Triggering event Exploration Integration Resolution	Sense of puzzlement Information exchange Connecting ideas Apply new ideas
Teaching presence	Design and organization Facilitating discourse Direct instruction	Setting curriculum and methods Sharing personal meaning Focusing discussion

Teaching presence is defined as "the design, facilitation, and direction of cognitive and social processes for the purpose of realizing personally meaningful and educationally worthwhile learning outcomes" (Anderson et al., 2001, p. 5). Garrison et al. (2001) further explained that teaching presence should involve precipitation and facilitation of learning through sustained and authentic communication. The social development theory helps further increase the significance of social presence in online learning as it states that "social interaction is vital to cognitive development" (Valenzuela et al., 2013, p. 95).

Teams

Early use of the word '*team*' denoted horses pulling together a plough or a stagecoach together. As horses pulled together in the same direction, they moved forward, and if they pulled in different directions, they would not get to the final destination. Hill (2001) defined a team as a group of people who are mutually accountable and have set performance goals and a strategy to achieve those goals. Likewise, Green (2003) defined a team as "a group of people pulling together for a common purpose, which they value" (p. 6). Kozlowski and Ilgen (2006) summarized definitions of teams as "(a) two or more individuals who (b) socially interact (face-to-face or, increasingly, virtually); (c) possess one or more common goals; (d) are brought together to perform organizationally relevant tasks; (e) exhibit interdependencies with respect to workflow, goals, and outcomes; (f) have different roles and responsibilities; and (g) are together embedded in an encompassing organizational system, with boundaries and linkages to the broader system context and task environment" (p. 79). Teams are often composed of individuals with unique knowledge, experience, and expertise which is not a guarantee of success. However, how these individuals work together providing an integrated team response can be a marker toward success (Gabelica et al., 2016). Lumsden et al. (2010) defined a team as a "diverse group of people" (p. 13) and gave some characteristics of a group; "all members help the group to interact and make progress on the task at hand."

Team Learning

Early research of team learning aimed to determine how to teach a large number of students while still maintaining the core values of teaching, which included deep discussions, decision-making, engagement, and feedback. Sibley et al. (2014) found that for a team-based learning to be effective to solve complex real-world problems, the team needs to be balanced, have team members with a wide range of skills, backgrounds, and personal experiences, include a large number of students (5–7), and the members must work together consistently. Team learning success as defined by Hill (2001) identifies four benchmarks to be deemed successful: improvement of skills at the individual level, less confusion or duplication of effort among team members, openness in sharing information and tasks, open communication about success and failures. Michaelson's foundational research in team learning was the impetus for a framework and methodology that promotes team-based learning (TBL).

Technology-Enabled Learning Environments

Technology-enabled learning environments are commonplace in online learning environments. Technology-enhanced learning is a learning process that is supported by technology applications, such as communicative software applications, learning management systems, or production tools. Land and Jonassen (2012) posited that designing a learning environment begins with identifying the goal of learning and creating learning activities and experiences that reciprocate real-world situations.

Social Presence in Online Learning

Social presence in teaching and learning environments can be a challenge to attain. When instructors and online learning environments are designed to allow learners to personalize and customize their social identities, social presence can increase (Shen et al., 2010). Group or team social presence can be affected by the size of the group or team, of which the optimal size is related to the complexity of social interactions that will be occurring. Bertucci et al. (2010) explained the complexity of group size and social interactions with these examples: (a) when individuals work in pairs, there are "two social interactions," and (b) when working in groups of four team members, there are "12 social interactions" to manage. Large groups may be problematic as all members may not be actively engaged in learning. Social loafing, defined by Aggarwal and O'Brien (2008), refers to the behavior that some engage in when they do not contribute to the group or complete desired outcomes. Social loafing tends to be more prevalent in large teams and can result in reduced effectiveness of team-based learning environments.

Akcaoglu and Lee (2016) further argued that a large team may contribute to attention overload of the team members due to the compounded influence of increased team interactions. Reduced attention affects the development of team cohesion, team morale, and quality of communication. Conversely, smaller teams can result in decreased repetitiveness, increased sense of community, higher-order thinking, and increased learner outcomes. Lowry et al. (2006) espoused other benefits of small teams, such as increased quality of student-to-student communication and an increased willingness of individual students to interact with other team members.

AbuSeileek (2012) reported that groups of two to five students have higher performance than those of six to seven students. Team size influences the members' level of shared social and personal identity, social interactions, and participation for effective team-based learning. Smaller teams are preferable for the increased outcome of quality work and communication (Alnuaimi et al., 2010).

Evaluating Social Presence in Online Team Learning

Evaluation of social presence in online team learning should include user interface, social cues, learning interaction, learning performance, and the constructs of social presence, inclusive of co-presence, intimacy, and immediacy. Zhao (2003) defined co-presence in a technology-based environment as the human-to-human interactions that give "the sense of being together with other people in a technology-generated environment" (p. 445). Positive feelings regarding co-presence contributes to increasing team members' participation and interaction. Social cues and user interface were viewed by Wei et al. (2012) to be significant environmental factors that influence social presence. The user interface evaluates the team members' perception of a learning system and qualities of social cues mediated by the online learning system. Wei et al. (2012) reported that among 552 students, user interface and social cues have a direct effect on social presence ($\beta = .324$, $\beta = .506$), social presence had a direct effect on learning interactions ($\beta = .776$), and learning interactions had a direct effect on learning performance ($\beta = .632$). Implications from this finding highlight the need for online learners to familiarize themselves with the online learning environments and the requirements for successful team learning at the beginning of the learning process. When learners are familiar with the learning environment, this familiarity can increase their transmission of social cues, which in turn increases social presence.

Technology Supports to Increase Social Presence

Technology affords effective ways to increase social presence for digitally mediated team learning. Through video, audio, and whiteboard applications, instructors can purposely design ways to support social presence.

Synchronous Videos

Synchronous video is live video communication. Live video captures what is taking place as it is taking place. Synchronous video is typically viewed through various online platforms such as Zoom, Adobe Connect, the live video function of Blackboard Collaborate, YouTube Live, BigBlueButton in Canvas, Webex, and Teams. The live video platforms can be more expedient and help establish others as being "real" and "there" enabling people to virtually see each other in real-time. Live video contributes to improved engagement and increased instructor presence and supports the development of a community of learning as a result of the inclusion of verbal and nonverbal communication. Typically these live platforms can support the transfer of files and other data that may further foster shared communication.

Due to facial, physical, and other nonverbal clues, the face-to-face discussions are deemed more authentic by students. Clark et al. (2015) further stated that these clues mirror what happens when meeting in the same physical environment. There are immediate social interaction, increased engagement, and participation in team-based learning. For effective team learning when using synchronous video, Clark et al. (2015) indicated that there should be a creation of social space that builds a strong sense of community that includes: (a) establishment of rules and (b) identification of group members ideals and beliefs, and sociability. The environment should build respect and trust between all team members.

Synchronous video interactions can include instruction that explains content or describes learning tasks. Further it can be used for prompt instructor feedback and better student–teacher interaction and communication (Karal et al., 2011; Rehn et al., 2016). In synchronous interactions, the teacher can influence behavioral, affective, and cognitive learning outcomes. The instructor's presence in synchronous video can support an environment where the cognitive and social presence can thrive.

Asynchronous Videos

Asynchronous videos can be described as video-recorded learning content outside of the classroom, prepared by an instructor, adopted from or created by a third party, and administered to learners as pre-class, in-class, or post-class learning content

(Ishak et al., 2020). There are different types of asynchronous videos such as demonstration, learning glass, pen tablet, interview, talking head, classic classroom, digital drawing board (Khan-style), computer coding sessions, whiteboard, and slides (Choe et al., 2019; Chorianopoulos, 2018) (Fig. 1).

Different platforms utilized to share asynchronous videos include: YouTubeEdu and iTunesU or learning management systems (LMSs) such as Canvas and Blackboard. LMSs often offer options to upload or record videos and offer tutorials to guide the instructor in making or uploading recordings. Asynchronous videos can be pre-recorded by the instructor or students and shared with team members to watch at their convenience. Video embedded in asynchronous discussion, known as a voice thread, can foster multimodal discussions and communication to make the online discussion experience more authentic. Pre-recorded lectures were found to increase social presence cues. Video feedback from the instructor affords expression of nonverbal cues, which increases a sense of closeness and effective teaching and learning experiences.

Choe et al. (2019) viewed that effective pedagogy in teaching online is different from face to face interactions, thereby requiring instructors to develop new online teaching skills. These skills may include: (a) developing presentations for an online environment; (b) using cameras and virtual backgrounds, and (c) how to effective use of multimedia resources. Understanding and applying multimedia learning principles (Mayer, 2009) can improve asynchronous video instruction, such as video lectures, which may increase team learning, improve learning outcomes, and students manage cognitive load (Choe et al., 2019). When included in team learning, asynchronous videos help create a balance between the affective, psychomotor, and cognitive domains (Moridani, 2007). Balancing of these domains in teaching helps in increased learner performance. The benefits of asynchronous videos can provide learners with a means to review content.

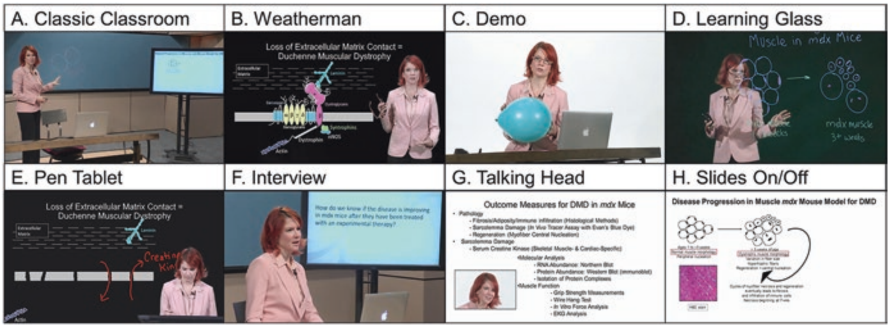

Fig. 1 Types of asynchronous videos (Choe et al., 2019). (**a**) Classic classroom, (**b**) weatherman, (**c**) demo, (**d**) learning glass, (**e**) pen tablet, (**f**) interview, (**g**) talking head, (**h**) sides on/off

Digital Storytelling

Digital storytelling is an instructional approach to build social presence in teams. Shelby-Caffey et al. (2014) identified that digital storytelling told a person's point of view, drew the viewer's attention, and stirred an emotional connection, which increased social presence. It combines images, voice, music (Smeda et al., 2014), video, animation, graphics, and web publishing (Mellon, 1999) to tell a story. It helps to establish a team member or learner as a "real" person. Other educational benefits of digital storytelling with teams include: (a) increased innovative learning and teaching practices, (b) increased learning outcomes, (c) increased learners' motivation, (d) building of constructive learning environments by instructors, (e) facilitate an integrated approach to curriculum development, (f) engage learners in deep learning, and (g) development of problem-solving skills through collaboration and student–student interaction.

Tools to design digital storytelling include (a) Moviemaker (Smeda et al., 2014), (b) WeVideo (Karakoyun and Yapici, 2016), (c) Adobe Slate, and (d) ShowMe Interactive Whiteboard (Leshchenko et al., 2017). When digital storytelling is incorporated in team learning, the team members take active roles and analytical roles integral in the learning cycle. Mendez et al. (2015) report that "when students tell their own stories, they develop a stronger relational integration of theories and contextualize the concepts they learn" (p. 32).

Feedback

Providing feedback is an integral part of teaching and learning (Hennessy and Forrester, 2014). Video feedback has enabled instructors to be more effective in increasing social presence in online learning because they created a sense of closeness with students. Video recordings of evaluation of assignments can contribute to increased understanding of the feedback provided. Video feedback should help the learner view the feedback as part of an ongoing conversation about their learning process (Thompson and Lee, 2012) in synchronous and asynchronous learning. Likewise, audio feedback affords the same opportunity for reflection and may facilitate students reviewing their work at the same time they are listening to the feedback (Olesova et al., 2011).

Social Media Platforms

Social networks increase social learning, communication, and collaborative learning (Rasiah, 2014; Balakrishnan and Gan, 2016). Twitter, Myspace, and Facebook provide just-in-time interactions and are further viewed as useful tools to facilitate communication with learners, effectively manage educational projects, and provide communication platforms for learning (Kim et al. 2018). Wang et al. (2014), in their research on the use of Facebook to create a social presence in online learning, investigated how students used Facebook for academic purposes. They found that it helped in group formation and facilitation and increase in student–student and student–instructor interactions. For the effective use of social media platforms, the instructors need to understand the learners' social and academic backgrounds to design quality lesson plans and learning assessments (Rasiah, 2014) and incorporate learning theories effectively.

Facebook, the most commonly used site by people of different age groups, has been used as an online team-based learning platform, and it has (a) cultivated positive learning experience, (b) enhanced instructor–student interactions, (c) contributed to facilitating learner relationships, and (d) increased social presence through virtual interactions (Everson, et al., 2013; Rasiah, 2014). Other benefits of social learning platforms include learners' developing team working skills as they create their learning spaces to resolve learning challenges.

Wikis are another online tool for facilitating collaborative knowledge building. Wikis' online recording capabilities trace written interactions, changes, and progress in collaborative work. The adaptation of the different social media platforms influences the education sector's approach toward online learning and teaching. Rasiah (2014) viewed that higher education has provided transformational learning and teaching opportunities through social media platforms. Social learning processes occur as the team members collaborate, connect, and interact with knowledge construction processes.

Conclusion

Social presence is essential for teams working online. There are many ways for instructors to both initiate and increase social presence in the teaching and learning environment, including sending a welcome letter at the beginning of a course of instruction, creating a personalized introduction, providing prompt feedback (Wang, 2010), and scaffolding and engaging with learner comments and interactions (Fahy, 2003). Use of social media applications such as Twitter and Instagram can aid in the sharing of ideas, files, tasks, and screen sharing. Through these tools, students are also able to discuss, negotiate, and clarify ideas promptly to arrive at a final solution (Huang, 2017). Further, synchronous tools such as interactive whiteboards, screen sharing, and video and audio chats can be integral tools for use with pedagogical strategies that maximize the strengths of team-based learning, while minimizing the drawbacks (Gautreau et al., 2012). It is evident that social presence is essential in team-based learning and many factors affect and influence the application of technological applications mentioned to increase social presence, thus affecting the creation and management of meaningful online learning experiences in technology-enabled learning environments.

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Glossary[1]

Term	Acronym	Definition with citation
Augmented reality	AR	Augmented reality (AR) refers to incorporation of 3D virtual objects into a 3D real environment in real time (Azuma, 1997).
Case-based learning	CBL	CBL uses "...a story, describing or based on actual events and circumstances, that is told with a definite teaching purpose in mind" (Lynn, 1999, p. 2).
Collaborative learning	CL	"...students working in pairs or small groups to achieve shared learning goals... learning through group work rather than learning by working alone" (Barkley, Cross, & Major, 2014, p. 4).
Computer-mediated communication	CMC	"Any form of information humans present or exchange by means of a computer" (Sigrid, 2008, p. xxxvii).
Computer-supported collaborative learning	CSCL	"Computer-supported collaborative learning (CSCL) refers to collaborative learning that is facilitated or mediated by computers and networked devices. CSCL can occur synchronously, with learners interacting with each other in real time (e.g., a chat room), or asynchronously, with individual contributions stretched out over time (e.g. e-mail exchange)" (Stahl, Koschmann, & Suthers, 2014, p. 479).
Cooperative learning (cooperative work)	CopL	"A set of processes which help people interact together in order to accomplish a specific goal or develop an end product which is usually content specific. It is more directive than a collaborative system of governance and closely controlled by the teacher" (Panitz, 1999, p. 5).

[1] DeMara, R.F., Campbell, L.O., Hartshorne, R, & Spiegel, S. (2019). *Report from the NSF synthesis and design workshop: Digitally-mediated team learning*. National Science Foundation (NSF) Project 825007. https://www.nsf.gov/awardsearch/showAward?AWD_ID=1825007

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Term	Acronym	Definition with citation
Digitally mediated	DM	Transacting communication or in development of a product or process through digital means.
Digitally mediated team learning	DMTL	Encompasses cooperative learning in a digital classroom-based synchronous setting. Work products and knowledge are co-constructed utilizing common resources and mutually shared views of the exercise. Every role is valued and members can adopt shifting roles during the activity. The focus of DMTL can include STEM problem-solving and design activities within a classroom setting in real-time. During the DMTL activity, the instructor supports rather than directs the learning experience via the shared virtual space. DMTL leverages data analytics and the potential of machine learning to advance learning outcomes and scalability.
Extended reality	XR	"Extended Reality (XR) is an umbrella term encapsulating *Augmented Reality* (AR), *Virtual Reality* (VR), Mixed Reality (MR), and everything in between" (Extended Reality XR, 2019).
Flipped classroom or flipped learning	FC	"FC...is a... pedagogical method, which employs asynchronous video lectures and practice problems as homework, and active, group-based problem solving activities in the classroom. It represents a unique combination of learning theories once thought to be incompatible—active, problem-based learning activities founded upon a constructivist ideology and instructional lectures derived from direct instruction methods founded upon behaviorist principles" (Bishop & Verleger, 2013, p. 2).
Individual readiness assurance test	IRAT	"The first in-class activity in each instructional unit is an individual readiness assurance test (iRAT) over the material contained in the preclass assignments. The tests typically consist of multiple-choice questions that enable the instructor to assess whether students have a sound understanding of the key concepts from the readings. As a result, the questions should focus on foundational concepts, not picky details, and be difficult enough to stimulate team discussion" (Michaelsen & Sweet, 2008, p. 17).
Learning analytics (higher education)	LA	Interactions for learning optimization (human being focused to find patterns). Informing instructors and coaches "Learning Analytics is the development and application of data science methods to the distinct characteristics, needs, and concerns of educational contexts and the data streams they generate for the purpose of better understanding and supporting learning processes and outcomes" (Wise, 2019, p. 119). "Learning analytics is the measurement, collection, analysis, and reporting of data about learners and their contexts, for the purposes of understanding and optimizing learning and the environments in which it occurs" (Siemens, 2013, p. 1382).

Term	Acronym	Definition with citation
Massive open online course	MOOC	"...the majority of MOOCs are virtual, distributed classrooms that exist for six to ten weeks at a time. These MOOCs are structured learning environments that emphasize instructional videos and regular assessments, centralizing activities on a single platform" (Kizilcec, Piech, & Schneider, 2013, p. 170).
Mixed reality	MR	"Mixed reality (MR) refers to the incorporation of virtual computer graphics objects into a real three dimensional scene, or alternatively the inclusion of real world elements into a virtual environment" (Pan, Cheok, Yang, Zhu, & Shi, 2006).
Natural language processing	NLP	Natural Language Processing (NLP) is "the analysis of human language using computers, providing the means to automate discourse analysis" (McNamara et al., 2017, p. 94).
Peer learning (Peer-to-peer learning)	PL	"...the acquisition of knowledge and skill through active helping and supporting among status equals or matched companions. It involves people from similar social groupings who are not professional teachers helping each other to learn and learning themselves by so doing" (Topping, 2005, p. 631).
Problem-based Learning	PBL	"...learning that results from the process of working toward the understanding or resolution of a problem. The problem is encountered first in the learning process!" (Barrows & Tamblyn, 1980, p. 1).
STEM education		The study of the pedagogy and andragogy of Science, Technology, Engineering, and/or Math (STEM). In this context STEM can be inclusive of all subjects or it can be a singular or combination of the subjects. "...STEM education has been defined as 'a standards-based, meta-discipline residing at the school level where all teachers, especially science, technology, engineering, and mathematics (STEM) teachers, teach an integrated approach to teaching and learning, where discipline-specific content is not divided, but addressed and treated as one dynamic, fluid study'" (Brown, Brown, Reardon, & Merrill, 2011, p. 6).
Team		A group of people working together with a shared purpose. Moves beyond a group or grouping "...a group of people working together to achieve a common purpose for which they hold themselves mutually accountable" (Scholtes, Joiner, & Streibel, 2003, pp. 1–2).
Team readiness assurance test	TRAT	"Once students turn in their individual tests, they then take the exact same test again, and must come to a consensus on their team answers. Importantly, teams must get immediate feedback on their performance, currently best achieved using scratch-off forms in the immediate feedback assessment technique (IF-AT)" (Michaelsen & Sweet, 2011, p. 43).

Term	Acronym	Definition with citation
Team-based learning	TBL	"...an active learning and small group instructional strategy that provides students with opportunities to apply conceptual knowledge through a sequence of activities that includes individual work, teamwork and immediate feedback. It is used with large classes (4100 students) or smaller ones (525 students), incorporating multiple small groups of 5–7 students each, in a single classroom" (Parmelee, Michaelsen, Cook, & Hudes, 2012, p. e725). "TBL employs a structured three-phase sequence: (1) preparation, during which learners study an advance assignment defined by faculty, (2) readiness assurance, where learners demonstrate knowledge through individual and group readiness assurance tests (RATs), and (3) application, when learners apply course concepts to problem-solving exercises designed by faculty and analyzed by teams" (Koles, Stolfi, Borges, Nelson, & Parmelee, 2010, p. 1739). Often employed in medical education.
Virtual reality	VR	"Virtual reality (VR) is the use of computer graphics systems in combination with various display and interface devices to provide the effect of immersion in the interactive 3D computer-generated environment" (Pan, Cheok, Yang, Zhu, & Shi, 2006).

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Subject Index

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