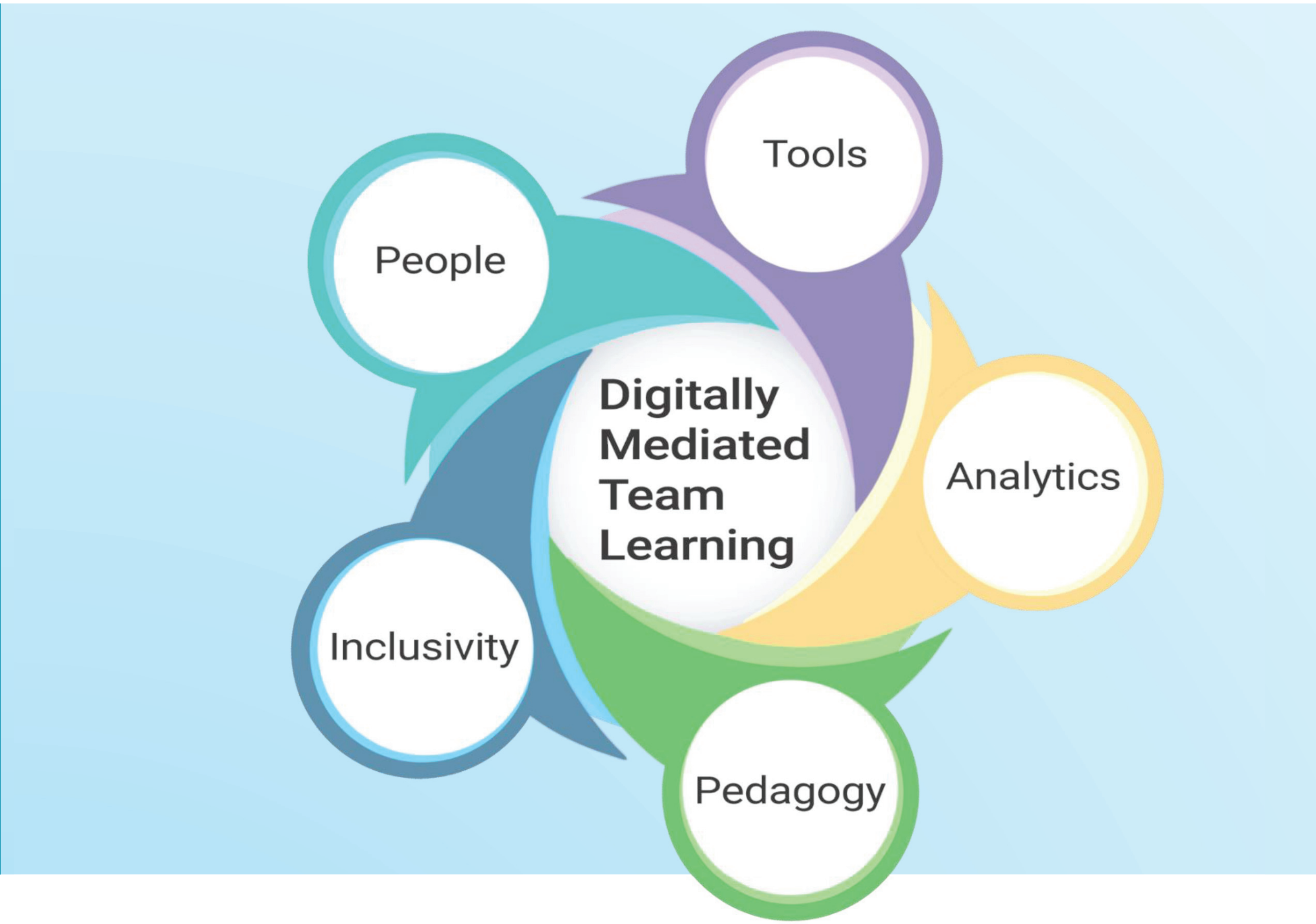
Report from the NSF Synthesis and Design Workshop: Digitally-Mediated Team Learning



University of Central Florida, Orlando, FL, March 31 – April 2, 2019

R. F. DeMara (PI), L. O. Campbell (Co-PI), S. Spiegel (Co-PI), R. Hartshorne (Co-PI),
Track Editors, and Workshop Participants as identified herein

This material is based upon work supported by the National Science Foundation under grant 1825007. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Suggested Citation: R. F. DeMara, L. O. Campbell, R. Hartshorne, and S. Spiegel, "Report from the NSF Synthesis and Design Workshop: Digitally-Mediated Team Learning," National Science Foundation (NSF) Project 1825007, September 24, 2019. Available at: https://www.nsf.gov/awardsearch/showAward?AWD_ID=1825007

Abstract

The purpose of the workshop on Digitally-Mediated Team Learning (DMTL) was to convene, invigorate, and task interdisciplinary science and engineering researchers, developers, and educators to coalesce the leading strategies for digital team learning with a focus on synchronous delivery of STEM problem-solving and design activities especially within classroom settings. A primary deliverable from the workshop is identification of one-year, three-year, and five-year research objectives as roadmaps for highly-adaptable environments for computer-supported collaborative learning within STEM curricula. Collaborations during the workshop aimed to identify near-term and future research directions to facilitate adaptable digital environments for highly-effective, rewarding, and scalable team-based learning.

An emphasis of the workshop included the personalization of collaborations among diverse learners by automating the identification and utilization of learners' efficacies and knowledge gaps to create complementary collaborative teams that maximize avenues for peer teaching and learning. The workshop targeted the utilization and efficacy of next-generation learning architectures through a focus on instructional technologies that included technical objectives of: (a) identifying new research in learning analytics required to automate more optimal composition, formation, and adaptation of learner design teams; (b) detecting advances in physical and virtual learning environments that can promote more effective and scalable observation and assessment of learner teams in real-time; (c) distinguishing data mining techniques to leverage devices such as monitors, trackers, and automated observations to increase efficacy of team learning; and (d) extending collaborative learning technologies to broaden participation and achievement of diverse learner groups, including women and other underrepresented and underserved populations in STEM.

Workshop attendees agreed that there are numerous untapped opportunities for online instructional environments to engage, orchestrate, and assess STEM design and problem-solving teams, especially within classroom settings. Proven methods, inexpensive technology, and digitally-receptive students combine for timely feasibility of such an effort given the widespread adoption of mixed-mode delivery and demands of enrollment scalability. Attendees unanimously recognized the value of a roadmap for DMTL created within a workshop setting and then refined through continued research. Indeed, attendees expressed interest in conducting multi-institutional surveys, as a one-year research objective, aimed at establishing consensus in best practices/standards for establishment of next-generation DMTL learning architectures. Follow-on 3-year research could then be focused on implementation and 5+-year research on refinement of these architectures (e.g., by enhancement via machine learning/AI for enhanced scalability and efficacy), as well as evaluation via longitudinal studies.

Specifically, some key 1-year research objectives are use of surveys for unifying research evidence on efficacy of real-time classroom-based DMTL across delivery modalities, and assembling a glossary of inclusivity terminology, methods, and metrics relevant to DMTL. Key 3-year research objectives include creating reusable and adaptable DMTL activities with engaging learner interfaces supporting STEM-

specific tools (e.g. models, programming, equations, simulations) and creating a clearinghouse showcasing high-impact DMTL practices available to the public. Finally, key 5+-year research objectives include applying and extending machine learning/AI technologies within DMTL to: (a) longitudinally suggest (or automatically construct) team learning activities personalized to the learners at-hand, (b) hybridize DMTL with Intelligent Tutoring Systems (ITS) whereby ITS agents have co-instructor roles, and (c) adapt an extended-reality environment to spontaneously insert virtual teammates at pivotal moments, such as when students are retreading the same ground or have embarked on a wrong path.

Table of Contents

Chapter 1

Introduction

As a joint effort between the University of Central Florida (UCF), the Worcester Polytechnic Institute (WPI), and the Colorado School of Mines, the NSF-Sponsored *Digitally-Mediated Team Learning (DMTL) Workshop* took place at the University of Central Florida from March 31 through April 2, 2019. The purpose of this workshop was to convene researchers, educators, and practitioners to advance transformative pedagogical approaches for technology-enhanced team learning within STEM disciplines for both secondary grades and college levels. During the workshop, interdisciplinary data science and STEM researchers, developers, and educators identified future research directions towards adaptable digital environments for effective and scalable team-based learning in classroom settings while advancing personalized learning and empowering equitable participation from diverse learners.

The objective of this workshop was to determine one-year, three-year, and five-year plans for key research and practice considerations related to the integration of highly-adaptable digital learning environments in STEM teaching and learning, as presented within this White Paper. The White Paper provides a unifying roadmap for the future of the field, including the design, development, implementation, and evaluation of digitally-mediated team-based pedagogies, and is composed jointly by the organizers and participants of the workshop, as a comprehensive manuscript to capture and formalize the interactions which took place during the workshop.

Vision of Change

Team design, group problem solving, and project collaboration have always been prominent attributes of STEM education and within professional practice of STEM fields. These are manifested throughout STEM curricula as laboratory components, course projects, and even Senior Design courses which frequently rely upon team-based learning. Especially in the last two decades, and into the foreseeable future, team design skills are receiving increasing focus as the complexity of science and engineering skills taught in degree programs and deployed in practice. The rising tide of system design complexity necessitates future graduates in STEM fields to function effectively as specialists who also work well together within a diverse team during product development and research. Thus, the advancement of both mobile and forward-looking educational technologies demonstrating the potential to support team-based instruction is increasingly vital and continues to be of broad impact across STEM fields.

Specifically, this workshop pursued the following vision of change:

Advance next-generation learning architectures by convening researchers, developers, and educators to participate in the following four synergistic workshop tracks for team-based instructional innovations:

Track 1: Facilitating Team Learning in Real-time via Online Technologies

Track 2: Personalizing Collaborative Learning through Analytics
Track 3: Supporting Digital Teams using Active Pedagogical Strategies
Track 4: Empowering Equitable Participation through DMTL

The use of a track-based organization of the DMTL Workshop maximized the likelihood of adequate time spent discussing and considering the needs at-hand by explicitly targeting all aspects of the team-learning process. Tracks 1 and 3 focused on identifying specific technological applications and pedagogical strategies to support the delivery of high-quality team-based instruction, with an emphasis on real-time monitoring of student performance: Track 1 focused on developing new technological platforms, or leveraging existing platforms to achieve this goal, while Track 3 focused on embedding proven and emerging pedagogical strategies in team-based learning. Track 2 sought to optimize the initial team formation based on the learner profile (strengths and weaknesses) of each student, as established through data mining of assessments. Finally, Track 4 focused on developing strategies for equitable learning and inclusion of all students, especially those who may traditionally be underserved or underrepresented in STEM fields. The track-based approach was expected to convene experts from already-established fields, such as Computer-Supported Collaborative Learning (CSCL), Team-Based Learning (TBL), and Learning Analytics (LA), who may rarely attend conferences outside of their specialization, with the goal of both broadening the views of the participants and producing synergy both within and between workshop tracks.

Workshop Organization

The two-and-a-half-day workshop addressed the design, development, implementation, and evaluation of DMTL in the K–20 educational landscape. The complete workshop flow and agenda is provided in Appendix B. The initial half-day of the workshop consisted of technical overview and networking activities which began on a Sunday afternoon to allow a soft-arrival requirement for those traveling from remote locations in order to attend. These included an optional poster session for those wishing to present their Position Paper in a poster format. The poster session also provided an optional social mixer and reception initiated by the Dean of the UCF College of Engineering and Computer Science. On Monday, the workshop sessions commenced after a keynote address spanning all four tracks and outlook of the field to motivate the workshop. Parallel tracks continued throughout the day. Members of the Program Committee who served as the Track Chairs also designated breakout sessions from each track so that elements of the White Paper received sufficient time to be emphasized. The day ended with tours of new active learning space infrastructures and facilities that could support various aspects of DMTL. Tuesday's sessions began with a keynote address followed by a track debrief by each track chair to the entire workshop. The workshop breakout sessions commenced after a Reflection Debrief having emphasis on trends and progress made and areas to focus the remaining time on to maximize efficiency. After parallel tracks concluded, action committees were formed to complete the remaining steps needed after the workshop. Post-workshop activities consisted of remote completion of chapter drafts for this White Paper report.

The workshop was divided into four separate tracks. To maintain participants' focus during the workshop, each track was divided into five themes as listed in Table 1. Participants' assignments to tracks were based on the Position Abstracts and Expertise Profiles that they submitted in the months preceding the workshop. To ensure that each theme was addressed comprehensively, while also managing and focusing the track discussions, the workshop was divided into a series of one-hour breakout sessions, with each breakout session being devoted to a particular theme. To facilitate engagement and discussion, participants were provided with a template for each theme, in which they were to identify key concepts, areas of concern, and emerging points of discussion, which would in turn be used to develop this White Paper. Each track, and each theme within each track, had its own guiding questions to initiate discussion among participants. Details of each track are provided in Chapters 3–6, and further information on the structure of the workshop is provided in Appendix B.

Outline of Report

Chapter 2 provides an Executive Summary highlighting the major findings and recommendations. Chapters 3 through 6 discuss the detailed outcomes and recommendations regarding each of the four tracks on a theme-by-theme basis. Finally, Chapter 7 provides perspectives resulting from the workshop collaborations.

Table 1

Organization of Workshop into Four Tracks and Five Themes

	Track 1: Tools	Track 2: Analytics	Track 3: Pedagogy	Track 4: Inclusivity
Theme A	Activity Authoring	Types of Learner Data	Pedagogical Methods for Team Management	Engaging Communities of Diversity
Theme B	Student-Facing Delivery	Assessment Mechanics	Engagement & Accountability	Fostering Inclusivity
Theme C	Instructor Orchestration and Assessment Tools	Challenges for Optimization of Team Learning	Emerging Pedagogical Strategies	Equity & Diversity
Theme D	Educational Games/XR	Using Data to Provide Feedback	Faculty Development	Transferability & Sustainability
Theme E	Standards & Clearinghouses	Enhancing Cognitive Demand and Mastery of Learning Outcomes	Faculty & Student Orientation	Future Possibilities

Chapter 2

Executive Summary

During the first week of April 2019, a total of 84 STEM educators, learning scientists, and other higher education faculty from 44 universities, as well as eight industry partners assembled at the University of Central Florida to discuss and advance the current state and the future potential of digitally-mediated team learning. Four concurrent tracks were conducted with the intent to explore the tools, learning analytics, pedagogies, and inclusivity of DMTL in STEM. Each track consisted of six sessions with three to six guiding questions related to major themes in each of the tracks. Additionally, four leaders in related fields shared current research and challenges for the future of DMTL.

Workshop attendees agreed that DMTL is increasingly vital to the future of digital STEM learning, with numerous untapped opportunities for online instructional environments to engage, orchestrate, and assess STEM design and problem-solving teams in classroom settings in an era of proven pedagogical methods, inexpensive technology, and digitally-receptive students. Attendees saw value in a roadmap created for DMTL in a workshop setting, which could then be refined through interdisciplinary research spanning pedagogy, team sciences, machine learning, and more. These advanced fundamental design principles of DMTL including:

1) Leveraging instructional technology during group problem-solving activities which allows team members to adopt technical/leadership roles within a team to co-construct solutions to exercises through peer teaching and learning.

2) Having the instructor serve in a supportive role in which technology provides the instructor with real-time analytics on team progress, which can then be used to provide proper scaffolding/formative feedback for maximum efficacy in reaching learning goals.

3) Supporting equitable participation encompassing the human aspects of learning in a community of learners, which involves training of stakeholders (instructors, technology designers, and students) to uncover personal and perhaps unconscious biases regarding increased participation and sustainability in STEM.

With regards to these design principles, the remainder of this chapter provides a summary of the key objectives and challenges addressed within each of the four workshop tracks.

Track 1: Facilitating Team Learning in Real-time via Online Technologies

The past several years have witnessed an enormous growth in the potential and proliferation of enabling technologies for education, resulting in widespread availability and dramatic cost reduction in mobile hardware as well as educational software applications. Thus opportunities exist for each student to feasibly have a mobile device, with a variety of available options for both student-facing and instructor-facing interfaces. These include Google Docs which provide real-time editing capability (Zhou, Simpson, & Domizi, 2012), Etherpad which additionally provides traceability of student participation (DeMara, Salehi, Hartshorne, & Chen, 2017), InteDashboard™ which provides a platform for online team-based learning (O'Dwyer, 2018), CATME which features peer evaluation capabilities (Loughry, Ohland, & Woehr, 2014), and others mentioned in this report. Furthermore, new developments such as machine learning and extended reality promise continued technological expansion for years to come. However, as instructional technologies continue to be adopted by mainline instructors in STEM fields, the current lack of integrated workspaces, adaptable content, and scalability of research prototypes available to-date beckons to deploy these to realize their full potential for automation, reuse, and evaluation of their impact on learning outcomes. Herein, Track 1 seeks to provide a comprehensive overview of the current state-of-the-art in educational technologies, while identifying challenges and promising pathways to future research that may surmount these challenges. Namely, Track 1 has been organized into five themes: Activity Authoring, Student-Facing Delivery, Instructor Orchestration and Assessment Tools, Educational Games/XR, and Standards & Clearinghouses.

The first theme on Activity Authoring relates to authoring activities that allow for engaging and lucrative collaborative learning experiences including game-based learning, knowledge-building discourse, problem-based learning, online team-based learning, and collaborative problem solving. Next, the theme of Student-Facing Delivery identifies salient features of both practical and ideal student-facing platforms for DMTL, including embedded widgets for effective student–student and student–instructor communication. The theme of Instructor Orchestration and Assessment Tools then looks at ideal features of an instructor-facing dashboard, allowing for examination of team progress as well as student-level participation in real-time by the instructor, and generation of real-time feedback and instructor–student communication in a minimally-intrusive manner. The next theme of Educational Games/XR focuses on how recent developments such as extended reality can offer future possibilities where students are able to interact with content in an immersive environment. The final theme seeks to identify means of developing a clearinghouse containing a set of standardized DMTL lesson plans and activities for use by all instructors, similar to the IMS Global Learning Consortium available for use in K–12 education.

Track 2: Personalizing Collaborative Learning through Analytics

The purpose of this track is effective utilization of student data for team formation and personalized instruction including providing students with proper scaffolding and feedback. The track is mainly focused on determining which data to collect, how to collect and organize the data, and how to make best use of the data to optimize both team formation and the cognitive demand of assigned tasks. The track consists of five themes: Types of Learner Data, Assessment Mechanics, Challenges for Optimization of Team Learning, Using Data to Provide Feedback, and Enhancing Cognitive Demand.

The first theme on Types of Learner Data explores the wide variety of learner information that is available for collection, including student performance, preferences, demographics, discourse analysis, and even eye movement and brain waves; the goal is to identify standards for data collection and reporting in DMTL and develop the tools needed to accomplish this. The second theme of Assessment Mechanics focuses on data analysis techniques for collecting, organizing, and analyzing student data applicable in a noisy classroom setting. The third theme focuses on strategies for efficient data-based formation and evaluation of student teams. The fourth theme focuses on the development of tools (including AI) which can facilitate and accelerate feedback across varying dimensions of team learning. Finally, the fifth theme explores how data can be used to effectively align the cognitive demand of a learning task with student capabilities and place appropriate scaffolds within the task to maintain learner efficacy without excessive cognitive demand.

Track 3: Supporting Digital Teams Using Active Pedagogical Strategies

Past research in STEM education has embraced numerous pedagogical benefits of collaborative learning environments, including increased learner engagement and improved learner satisfaction with STEM content areas and majors. Collaborative learning environments extend opportunities for both knowledge acquisition and communicative experiences, as these facilitate deeper learning through the introduction of creative ideas and approaches via shared mental models and active participation in project- and problem-based instructional settings. These benefits and opportunities improve both knowledge acquisition and the development of communication skills. Additionally, more intensive teamwork and the development of soft skills can be enhanced through intentional peer, content, and instructor interactions that are supported via collaborative learning environments. As a result, there is a likely enhancement in the development of critical thinking, problem solving, decision-making skills, and learner engagement with STEM content. Track 3 explored pedagogical mechanisms to support, extend, and enhance settings that utilize digitally-mediated team and collaborative instructional approaches. The track was divided into five themes: Pedagogical Methods for Team Management, Engagement and Accountability, Emerging Pedagogical Strategies, Faculty Development and DMTL, and Faculty and Student Orientation.

The first of these themes explored the opportunity for a revision to STEM pedagogical approaches to provide student-centered, collaborative, and problem-solving opportunities, which has become increasingly necessary in STEM. The second theme focused on promoting student engagement in classroom and online settings through promotion of collaboration, teamwork, and accountability. The third theme discussed the role of emerging technologies, and the unique challenges they present related to pedagogical practices. The fourth of these themes looked at faculty development to help marry the knowledge of the STEM faculty with the desired pedagogical practices. The final theme was focused on the explicit instruction and deliberate practice needed to maximize student collaboration efficacy and adoption.

Track 4: Developing Inclusivity through DMTL

Developing inclusivity and equity in digital-mediated STEM learning environments is recognized as a promising and viable approach to broaden participation in STEM. Inclusivity of underserved populations is not limited to ethnicity and gender. Rather, areas of inclusivity discussed included: (a) ethnicity, (b) gender, (c) neurodiversity, (d) accessibility, (e) culture, (f) intercultural collaborations with global diversity, (g) geographical inequalities, and (h) intergenerational differences. Learners can hold membership in multiple groups; they are not limited to one identity or group identity. Rather, there is an intersectionality of multiple. At the intersectionality of multiple minoritized identities (e.g., [dis]ability, neurodiversity, race/ethnicity, gender, sexuality, socioeconomic status, religion, mobility, culture, and generations) in digital learning environments, there is a strong need for innovations, interventions, and research.

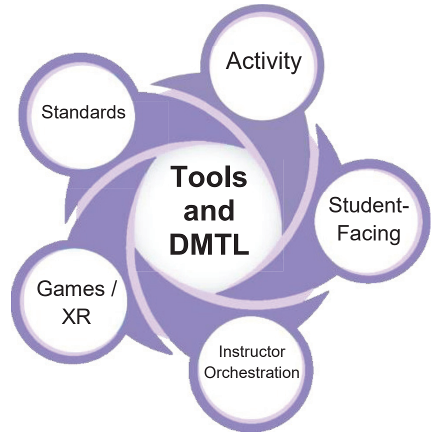
Aspects related to inclusive DMTL learning ecologies were identified and discussed. Participants recognized that existing learning technologies could be harnessed in new ways that increase participation from all learners to support broad engagement. Further, the design of new technologies that would support broader participation should be dynamic and inclusive.

Although new tools and ways to analyze resulting data are important aspects of broadening pathways in STEM, the human factor cannot be ignored. Training for instructors and students may result in reduced bias and more equitable learning. Embedding and fostering positive social skills in team learning could support students in the short term (classroom learning) and in the long term with skills that students will use beyond the classroom in their future STEM careers.

Researching the nexus of self-reported identity inventories, student perceptions' of outcome expectations, learning analytics, machine learning, and psychosociological factors could provide needed insights for developing sustainable STEM team learning frameworks, in which students gain self-efficacy and improved positive identity in STEM through successful team experiences. Current perspectives and future directions have indicated that DMTL would benefit from interdisciplinary investigations that include Learning Scientists, STEM Educators, Computer Scientists, and STEM Content Experts. These interdisciplinary teams could re-engineer current technologies and develop new ecologies and environments that would contribute to broadening and sustaining participation in STEM with reduced biases, offering high potential payoffs for advancing equitable participation.

Chapter 3

Track 1: Facilitating Team Learning in Real-time via Online Technologies



Introduction

Numerous high payoff research opportunities spanning the disciplines of *Computing Sciences, Intelligent Systems, Learning Sciences*, and *Social Sciences* can advance the development, refinement, and widespread use of novel, affable, and affordable instructional technologies capable of efficiently supporting digitally-mediated teams of learners. Namely, research under the umbrella term of *Digitally-Mediated Team Learning (DMTL)* leverages the convergence of efforts from the fields *of Computer Supported Collaborative Learning (CSCL)*, *Computer Supported Collaborative Work (CSCW)*, *Cooperative Learning*, *Peer Learning*, and *Team-Based Learning (TBL)* paradigms, which together have amplified potential to advance STEM learning from the perspective of new instructional technologies. This Track specifically addresses DMTL research which coalesces aspects across these fields to facilitate collaborative learning using real-time instructional technologies.

During the last decade, the need, benefits, and potential of DMTL have continued to increase (DeMara, Salehi, et al., 2017; Lin & Lai, 2013). For instance, the popularity of active learning in STEM using group activities has become heightened by the growing delivery of STEM courses via "flipped classroom" models or so-called "mixed-mode" delivery. Flipped instruction opens up a large opportunity for use of DMTL in classroom settings. Namely, mixed-mode delivery typically leverages hybridization of online instruction and face-to-face meetings whereby students conduct problem-solving activities in groups during the class meetings, rather than primarily listening to live lectures. Additionally, the availability of laptop and tablet computers, as well as mobile devices such as smartphones, offer low-cost technologies to advance the impact and scalability of DMTL. Thus, the scope of this workshop track focused foremost on the design of online instructional environments for engaging, observing, and assessing STEM design and problem-solving teams in real-time classroom settings, especially analytical problem-solving and design tasks conducted by student teams.

Guiding questions for this research track included:

- How is the interaction between the instructor and student teams supported when using future real-time collaborative technologies?

- What current DMTL-capable platforms (e.g., CATME, Etherpad, InteDashboard™, Socrative) provide desirable features to be adopted and extended in future frameworks?
- How can the underlying DMTL strategies be made adaptable to different device platforms spanning Mobile Device apps and Extended Reality (XR) environments spanning Virtual, Augmented, and Mixed Reality?
- How can teams and individual learners be monitored and observed in real-time?
- What are economic benefits (e.g., in terms of equivalent grader hours, number of instructors/faculty/facilitators) of scaling up DMTL to larger settings, as well as useful longitudinal assessment measures of learning benefits and skills of the future STEM workforce?

Figure 1 shows the scope of DMTL research covered in Track 1 from an operational perspective. Each constituent Theme, labeled 1A to 1E, has been annotated within the diagram as follows:

- *Theme 1A: Activity Authoring*
- *Theme 1B: Student-Facing Delivery*
- *Theme 1C: Instructor Orchestration and Assessment Tools*
- *Theme 1D: Educational Games / XR*
- *Theme 1E: Standards & Clearinghouses*

Starting with the *Authoring Phase* depicted in Figure 1, *Theme 1A: Activity Authoring* considers the state-of-the-art and 1, 3, and 5+ year research opportunities to advance the methods and interfaces by which instructors compose team active learning activities for STEM curricula. After structuring a team learning exercise, the *Delivery Phas*e commences wherein the instructor works with one or more teaching assistants to conduct the DMTL activity as depicted in Figure 1. Herein, the focus is on activities conducted by multiple groups of learners using Wi-Fi connected devices within a synchronous classroom setting. Students within each team collaborate using the student-facing DMTL interfaces and protocols whose research is addressed within *Theme 1B: Student-Facing Delivery* of this report. Meanwhile, the instructor is equipped with a computer-based user interface for real-time observation of the team learning activity and integrated assessment mechanisms, whose scopes of research are covered within *Theme 1C: Instructor Orchestration and Assessment Tools* in this White Paper document. *Theme 1D: Educational Games / XR* addresses the gamification strategies and advanced interfaces in DMTL, including their use as constituent approaches and technologies that crosscut wider use-cases such as cooperative informal science learning of STEM curricula. *Theme 1E: Standards & Clearinghouses* covers the research aspects of the *Indexing Phase*, including standards and conventions for interchanging, searching, and retrieving DMTL lesson plans, activities, questions, and results via database repositories and data clearinghouses that can increase transportability to aid propagation and benefit of DMTL across grade levels 6 to 20. Each of the aforementioned themes offers numerous research pathways to utilize and also advance new techniques, tools, assessments, and standards to enhance STEM learning at 1, 3, and 5+ year timeframes.

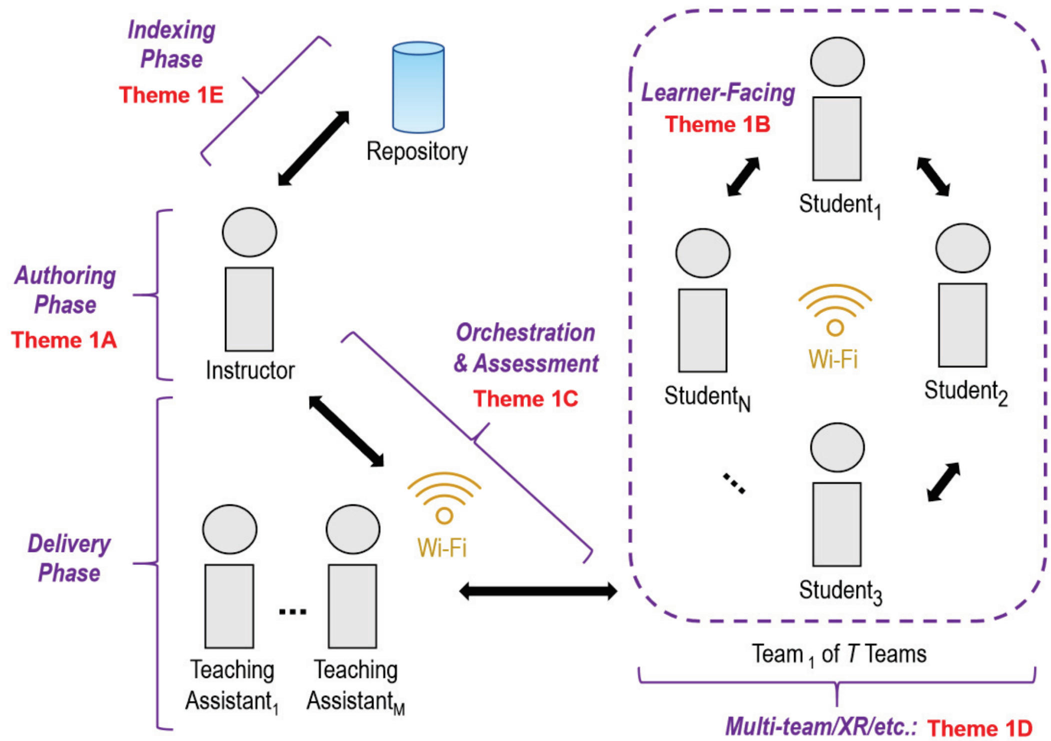
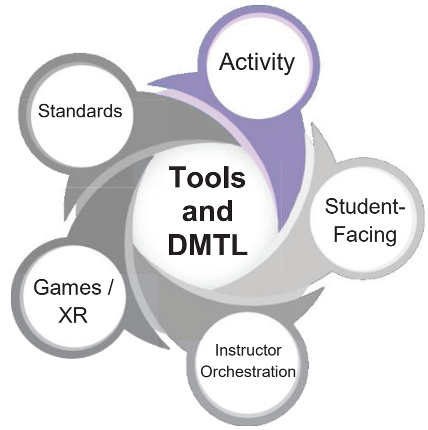


Figure 1: DMTL components and their relation to Track 1's Themes. Figure inspired and further extended from the HOWARD DMTL framework's operational view (Kazemitabar et al., 2016, Figure 1).

Theme 1A: Activity Authoring

Theme Editors: Leslie Bondaryk, Ronald F. DeMara, Jody K. Takemoto, and Tian Tian



Activity Authoring in DMTL spans several overarching research considerations:

- Which types of STEM design and problem-solving activities are most-suited for delivery as classroom-based activities using DMTL?
- How can those DMTL use-case archetypes be prioritized into 1, 3, and 5+ year research foci to achieve a layered development flow?
- How can DMTL Activity Authoring environments specify the essential parameters of collaborative learning activities using markup languages and/or conversion utilities to semi-automatically instantiate the authored content, including specifying linkages needed with the Learning Management System (LMS)?
- How can DMTL activities be efficiently maintained, including adaptations from semester-to-semester with methods to create “activity clones” (DeMara, Sheikhfaal, Wilder, Chen, & Hartshorne, 2019) which help reduce the feasibility of copying solutions from the previous use of the activity by the instructor or at other institutions?

Foremost, workshop participants agreed on the importance of authoring and cataloging activities that students show empathy and/or interest in doing, as previously suggested by Fink (2013). Namely, a key factor is that activities should elicit constructive feedback among peers and from the instructor. Research is needed for instructional technologies that can help instructors to scaffold good practice in teamwork in addition to the topic at-hand. The activity must allow for various roles to be meaningfully adopted by different team members while still letting them all learn the core subject matter (Belbin, 2012). To advance such research, a set of archetypal activities would be extremely useful to be delineated by assimilating current research results. Across these use-cases, some common challenges include determining optimal team size and composition (e.g., homogeneous vs. heterogeneous with respect to ability as well as demographics), as outlined by Fiore et al. (2017). Within that work, Fiore and colleagues highlighted various factors that could have an impact on this determination, including the nature of the task and whether the team members are only interacting with each other or with agents as well which are central to advancing authoring of DMTL activities and their effective deployment to learners.

Further challenges include determining the best way for all students to achieve maximal knowledge and skill competence through collaborative learning activities, balanced with allowing students freedom to choose their roles in the task, all while efficiently documenting contributions and moments of educational advance during the brainstorming/idea generation phase of the activity. A final discipline-specific research challenge arises from the need to develop and/or customize tools and projects that focus on team construction of domain-relevant artifacts: graphs, data, equations, etc., which is a high-priority near-term research task to address as opposed to the plain text collaboration environments today. At the other end of the research timeline, longer-term activity authoring research should include more robust and varied scaffolding activities to engage learners having a range of collaboration styles, ranging from the leader to the contemplative observer (Azzam, 2016). Systems should be developed to apply machine learning techniques to hone, refine, and personalize the Activity Authoring procedures and templates, such as providing the instructor with intelligent guidance for which activities are better suited for either individual or collaborative completion, or individual preparation complemented by student group completion.

A key challenge in DMTL is determining types of STEM design and problem-solving activities that can be implemented by new or existing technology that is accessible and affordable. This challenge has been substantially addressed from various perspectives, which have included such diverse solutions such as game-based learning (Mallavarapu et al., 2019), inquiry-based, knowledge-building discourse (Zhang, 2019), problem-based learning (Huang et al., 2017), use of a community deliberation process as an aid to team formation (Wen et al., 2017), distributed and generative design (White, Brady, Huang, & Stevens, 2019), online TBL (Clark et al., 2018; O'Dwyer, 2018), and collaborative problem solving activities in STEM classrooms (DeMara, Chen, Hartshorne, & Thripp, 2017). As shown in Figure 2, the Group Learning and Assessment at Significant Scale "(GLASS) learning flow is initiated by the instructor-led activities as indicated in the green-colored callouts. Once configured, the learning activity proceeds as a sequence of six steps comprised of 1) convening the teams, 2) disbursing the challenge problem, 3) technology-enabled collaboration between students, 4) reaching peer consensus on the correct answer, 5) submitting machine-gradable responses, and 6) presenting results to the learners for discussion" (DeMara, Salehi, et al., 2017, p. 12965). Each of these steps provides a framework for needed research on to advance the authoring of DMTL activities.

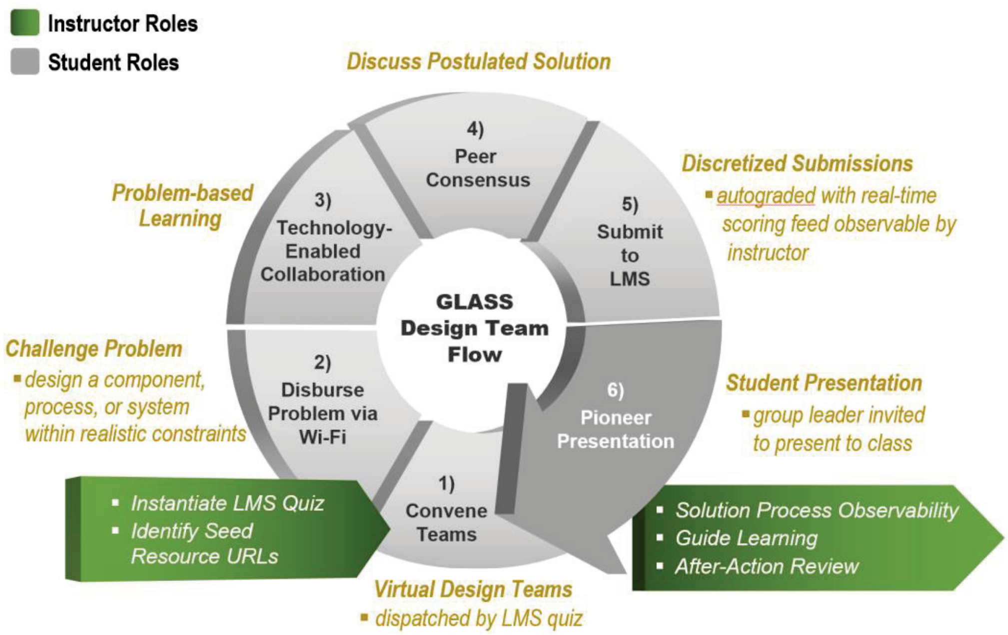


Figure 2: Learning flow for student-design team activity using GLASS (DeMara, Salehi, Hartshorne, & Chen, 2017).

As delineated via the steps shown in Figure 2, each student utilizes a laptop or tablet computing device to engage as a participant in the GLASS-based learning event. Utilizing an LMS-disseminated quiz, students are placed into random groups, and subsequently communicate and collaborate virtually, via Wi-Fi connectivity, with their team members, regardless of seating location in the physical classroom environment. Individual design team members then communicate and collaborate on solutions to a common challenge problem, using various technological applications to support the team-based environment, such as a digital whiteboard for composition of a final answer document as well as a chat platform to discuss varying perspectives on potential solutions to the challenge problem (DeMara, Salehi, et al., 2017). GLASS has been integrated or piloted in Electrical Engineering, Industrial Engineering, Mechanical Engineering, and Computer Engineering Courses, and has been effective with measured improvements in learning outcomes (DeMara, Salehi, et al., 2017). Student perceptions have been highly-favorable with 76 of 123 enrollees agreeing that "electronically-mediated groups can be beneficial in large enrollment classes," "I wish more courses would provide opportunities for digitally-mediated team learning," and "conducting a digitally-mediated team activity each week was fun" (only 0%, 1%, and 5% of respondents disagreed, respectively). However, integrated Activity Authoring tools are needed to facilitate the design and construction of the learning activity to reduce the instructors' burden to compose and maintain each component, which is currently done using disjointed tools in a piecemeal fashion. Namely, ad-hoc creation of team exercises is likely to result in students receiving substandard conveyance of ideas on a given topic or during the team learning event. Meanwhile, GLASS provides promising evidence on the feasibility of collaboration techniques for STEM problem solving activities with the face-to-face meetings of flipped-classroom delivery and framework to standardize such activity authoring tools.

In all of these approaches, a common objective is to engage students in technical content while enabling higher-level educational learning objectives including metacognitive thinking through collaboration, while at the same time providing an appropriate level of scaffolding throughout the activity. Authoring tool support for both are lacking or scant at-present. Further challenges facing Activity Authoring include lifecycle viewpoints such as efficient generation of Activity Clones (DeMara et al., 2019) and maximization of reusable content while maintaining academic integrity between multiple course deliveries and institutions. Activity clones are variations of the learning assignment which mitigate learner crosstalk and the availability of previous solutions to the same or similar learning activities. Activity clones are typically generated by modifying elements of the problem specification or permuting the quantities sought. A primary objective of Activity Cloning is for students to be afforded the opportunity to participate in comparable learning activities, while simultaneously reducing the propensity for them to share answers. Research which advances the automation of Activity Cloning is crucial for the success and sustainability of DMTL wherein the availability of viable clones significantly increases the likelihood that students attempt to conduct the activity, rather than merely locating the answers previously determined by others.

Currently, the state-of-the-art Activity Authoring support for DMTL is confined primarily to research prototypes utilizing diverse pedagogical approaches. These include adapting of LMS's, chat systems, code authoring editors, math and data-analysis tools, and text editors having low automation and reuse potential. Given its centrality to creation and use of practical DMTL activities, the theme of Activity Authoring constitutes a fruitful area of both near-term and long-term research that crosscuts many other themes in this Track, as delineated in Table 2.

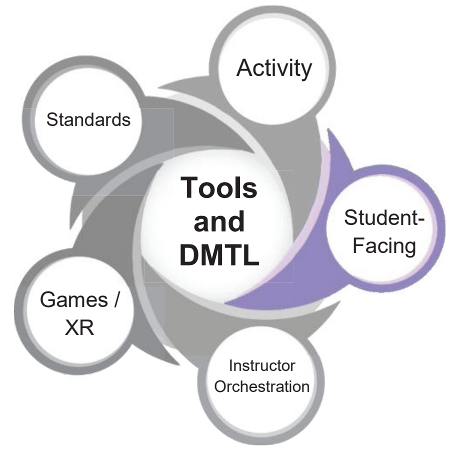
Table 2

Research Opportunities to Advance the Activity Authoring Aspects of DMTL

Dimension	1-Year Research	3-Year Research	5+ Year Research
Collaboration Strategies	• Conduct surveys to develop criteria which define a standardized DMTL framework of authorable elements for collaborative learning activities suitable for STEM learning. • Highlight differences / similarities of collaboration in STEM as opposed to other settings such as playgrounds and individualized makerspaces.	• Define and populate a taxonomy of DMTL use-cases that are most likely to improve student learning in STEM, based on the inventory from Year 1. • Research methods to leverage patterns of productive discourse to author activities which are suitable to enable learning analytics based on common ground of these two communities.	• Conduct studies of efficacy of how DMTL increases engagement with course redesigns moving from live-only lecture to mixed-mode delivery emphasizing group problem-solving activities during class time. • Develop machine learning techniques to hone, refine, and personalize the Activity Authoring of collaborative STEM lesson plans.
Delivery Processes	• Build a relational database of pedagogies, tools, data collection, analytics on Authoring Tools for DMTL, e.g., an integrated database that could be navigated easily and made accessible to the community via website.	• Extend lesson planning to include collaborative learning and reduce instructor burdens to utilize DMTL. • Create highly-engaging and maintainable activities for computer-supported collaboration that are reusable and adaptable by mainline instructors.	• Research the hidden but fundamental relationships between "optimal" sizes of groups, exercises, activity durations, etc. including longitudinal studies of learning outcomes, retention, and equitable participation.
Technology-Driven Advancements	• Extend the Collaborative Learning Activity Interoperability Standard (CLAIS): standard format for a team learning activity which defines a number of parameters [open to what they may be]; goal of helping faculty easily	• Develop visualization and STEM-specific tools (models, programming, equations, simulations) to make collaboration fun/easy/clear and elucidate pathways of ideas.	• Investigate how can social media/platforms be leveraged with team learning tools and activities? • Extend the enrollment size with Wizard/Agents that can modularize enrollments into

	import/export/reuse/modify/evaluate learning activities.	• Specifying an extensible interface beyond current LTI capabilities to define how tools can interchange data. • Develop authoring extensions that allow individual instructors to customize activities without having to rewrite them from scratch.	manageable numbers of groups. • Research the high-risk / high-payoff potential hybridization of DMTL with Intelligent Tutoring System (ITS) technologies for applications in cooperative learning whereby ITS agents are selected to actively augment the activities authored by the instructor. This could greatly increase scalability of peer-learning for large enrollments.

Theme 1B: Student-Facing Delivery



Theme Editors: Leslie Bondaryk, Ronald F. DeMara, Leilah Lyons, Brian O'Dwyer, Elliot Soloway, Jody Takemoto, and Jianwei Zhang

Efficacious delivery of student-facing interactions in DMTL involves multiple research considerations:

- What would suitable or even ideal student-facing user interfaces for DMTL look like?
- Process implementation: What are the essential widgets provided in a student-facing interface to implement DMTL processes: e.g., hand-raising, bannering, balloting, bookmarking, pinning of notes, strikethrough, submission, timing, and up-voting?
- Team collaboration: How do learners nominate team leaders or recognize team contributions (e.g., via pick lists, ratings systems, rubrics using blinded vs. open feedback, or even the need to support a range of these options)?
- Performance management: How do students receive feedback on their performance in DMTL environments?
- Social and emotional: How will improved student interactions in DMTL modulate soft skills and emotional intelligence development?
- Accessibility: What infrastructure is necessary to provide accessibility to all students?
- Future: What are state-of-art tools today for DMTL to identify a palette of desirable features to consider for further inspiration?

A key challenge to advancing student-facing elements of DMTL spans both conceptual dimensions of collaboration and technological constraints of delivery. The state-of-the-art approaches showing efficacy for student-facing tools span the following features: distinct interaction in solution-submission windows, traceability of student participation, activity navigation, and optionally the display of student-specific icons/credentials with participants' information. Major recognized works on these topics have separately addressed both the K–12 and higher education domains which form a constructive tension in DMTL with respect to the sophistication of user interface that learners can handle. For instance, within the K–12 domain, prototypical DMTL systems have been developed and fielded by Dede (Reilly & Dede, 2019), while Khaddage (2015) and Zhang (2019) provide other proven systems. In higher education classroom settings, products such as Intedashboard™ directly support the classic "TBL" Team-Based Learning paradigm promulgated by Michaelsen (Michaelsen & Sweet, 2011), while clicker tools such as those offered by Turning Point Technologies allow for anonymous participation and may also be used for educational games (Martyn, 2007).

An important dimension to consider for student-facing components of DMTL arises from the specific learning opportunities that can be supported by various hardware platforms and interfaces. These span browser-based collaboration environments for “Bring Your Own Device” (BYOD) platforms such as PC laptops, tablets and mobile devices, up through dedicated hardware including virtual reality platforms. Specification of instructional technologies that enhance the traceability of activities within learner teams, including advanced mechanisms for integrated and automated scoring, and annotation/organization of feedback is paramount. Careful consideration when implementing BYOD, considers the feasibility and/or the accessibility of devices for all of its learners.

There is consensus in the community that an ideal student-facing user interface would have the following essential characteristics: tractable to no learning curve, high usability for targeted age group, accessibility for students within Universal Design for Learning (UDL) guidelines (CAST, 2018). More advanced yet highly desirable characteristics would include interfaces which are more cognitively engaging, intrinsically collaborative, and remain interactive and viable throughout the DMTL exercise so as to improve outcomes through student engagement as suggested by Fink (2013). Such properties have been envisioned to necessitate student-facing features including widgets for communication such as voting and polling on fledgling ideas within the student team, digitally-mediated “hand-raising” mechanisms to seek instructor’s attention or guidance, freehand drawing and rudimentary revising, commenting, thumbtacks/sticky notes, and possibly even three-dimensional freehand drawings. Other student-facing aids to facilitate effective collaboration include chat windows, in addition to future research toward conversational agents or opportunities for feedback from both the system and instructor to maintain student engagement. Notwithstanding instructor-facing features, an ideal interface for the learner would support selected methods for blinded peer evaluation and address a key need to thwart social loafing while discouraging lone wolf behaviors (i.e., individuals preferring to submit on their own rather than sharing work with their teammates).

Although Google Docs and Google Classroom have been used extensively in education for the past several years, especially at the K–12 levels, future versions of these platforms or others may consider additional features which are valuable to realize a student-facing DMTL interface (e.g., text-based collaboration is challenging for lower-elementary grade students, the collaboration space provides limited traceability and playback capability, and there is minimal support for equation symbols used in higher STEM education). As an alternative to Google Docs, the Etherpad collaborative real-time editor has been used for implementation of GLASS (DeMara, Salehi, et al., 2017) and the collaboration interface of Rosé et al. (Ludvigsen, Law, Rose, & Stahl, 2017), offer similar ease-of-use to Google platforms but with the added benefit of individual-student traceability with color-coded text background and playback features. Other platforms such as InteDashboard™ (O’Dwyer, 2017, 2018), iPeer (Botha, Steyn, Weilbach, & Muller, 2018), CATME (Loughry, Ohland, & Woehr, 2014), and TEAMMATES (Ismail et al., 2013) have, in addition, placed an emphasis on peer evaluation with potential for acquisition of soft skills and perhaps emotional intelligence, and the Idea Thread Mapper (Zhang & Chen, 2019) allows students to co-organize discussion topics called wondering areas to trace their collective progress over time, including highlighting peers' upvoted questions and ideas with others. Finally, approaches such as Academically Productive Talk (Adamson et al., 2014) use conversational agents to scaffold collaborative discussions between learners.

A prototypical student-facing interface for DMTL developed by Rosé and her team at Carnegie Mellon University is shown in Figure 3 (Wen, 2016). As depicted on the left, a virtual collaboration space is realized using Etherpad to provide a whiteboard for collaboration during the team learning activity on tradeoffs associated with alternative energy sources for fossil fuels. A chat-style correspondence interface provided to learners is depicted on the right. The measures of success in the project related to evidence of the knowledge integration process and transactivity was measured in collaborative chat. Teams under the Transactivity Maximization Condition demonstrated better team performance by roughly 5% on the overall activity.

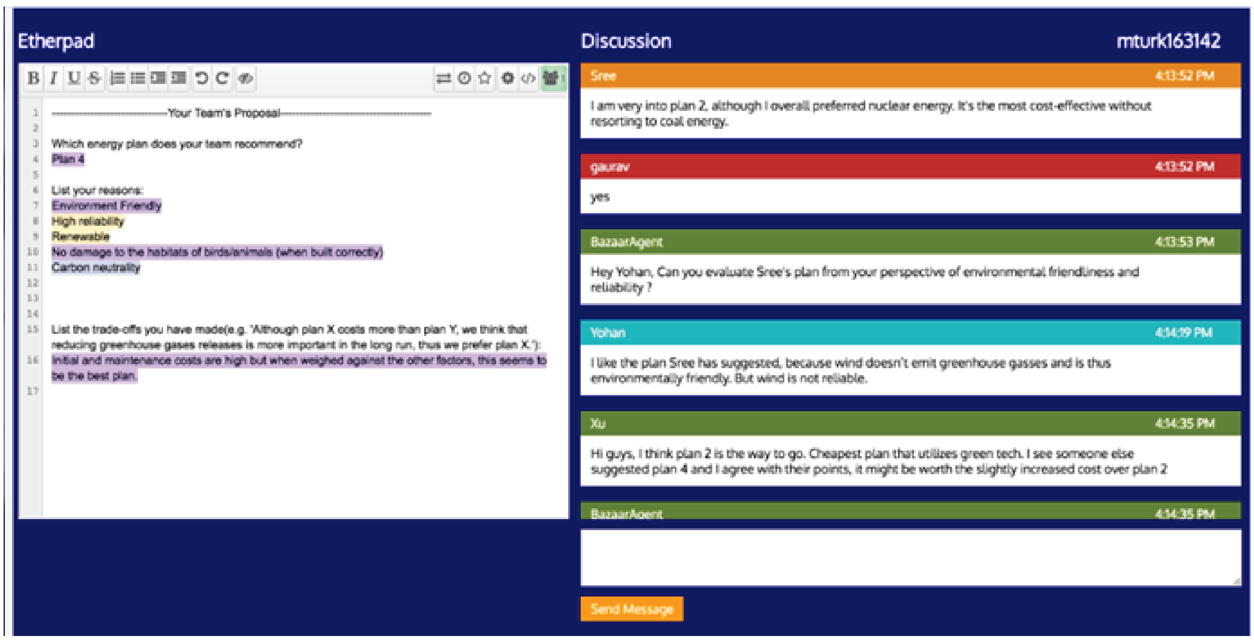


Figure 3: Prototypical Student-Facing DMTL interface (Wen, 2016).

Another archetypical student-facing baseline for DMTL in higher education STEM curricula geared toward problem solving and design tasks which has recently been proposed is GLASS (DeMara, Salehi, et al., 2017). GLASS seeks to maximize scalability and efficacy of student design teams and consists of students being randomly distributed into teams, with each team being assigned a problem set as a weekly in-class activity. Teams work collaboratively in Etherpad, which allows for individual-student traceability and real-time monitoring by instructors and teaching assistants. In GLASS, each of the student design teams receive the challenge problem, via the LMS, by clicking on the Question Launcher link, as depicted in Figure 4. Student design team members then negotiate various perspectives and aspects of proposed solutions, in an effort to reach a consensus that the team-developed solution is correct. For instance, Figure 5 illustrates one example of a somewhat typical design team interaction, with diverse contributions from individual team members. Highlighted are team collaborations to solve the design problem, as well as the consensus building processes, all strengthened by the documentation of learner participation. Thus, DMTL supports interactions that are not normally observable in conventional team problem-solving activities, where collaborative tools are not utilized. As a pedagogical incentive to contribute in the GLASS-based DMTL activity, each team selects a so-called Most-Valuable Peer (MVP) at the end of the session, who is awarded extra credit for outstanding contributions to the activity (DeMara, Salehi, et al., 2017).

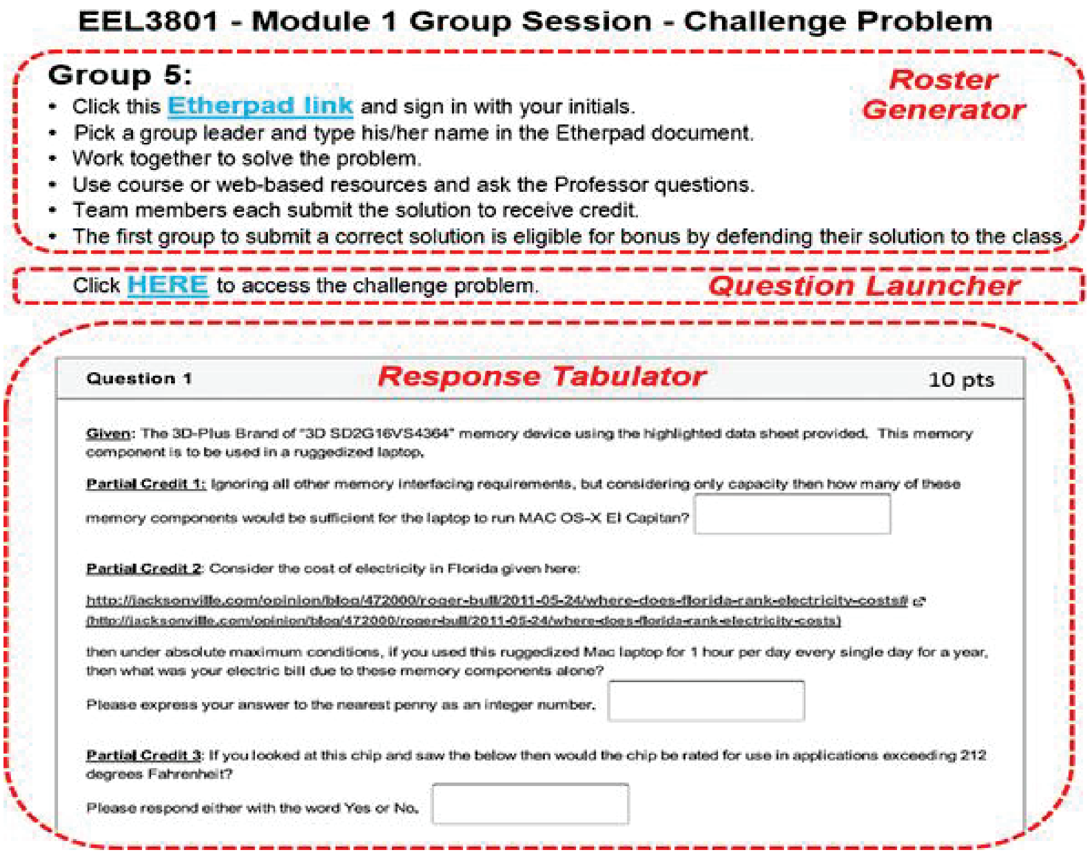


Figure 4: Structure of LMS Quiz components used in GLASS (DeMara, Salehi, Hartshorne, & Chen, 2017).

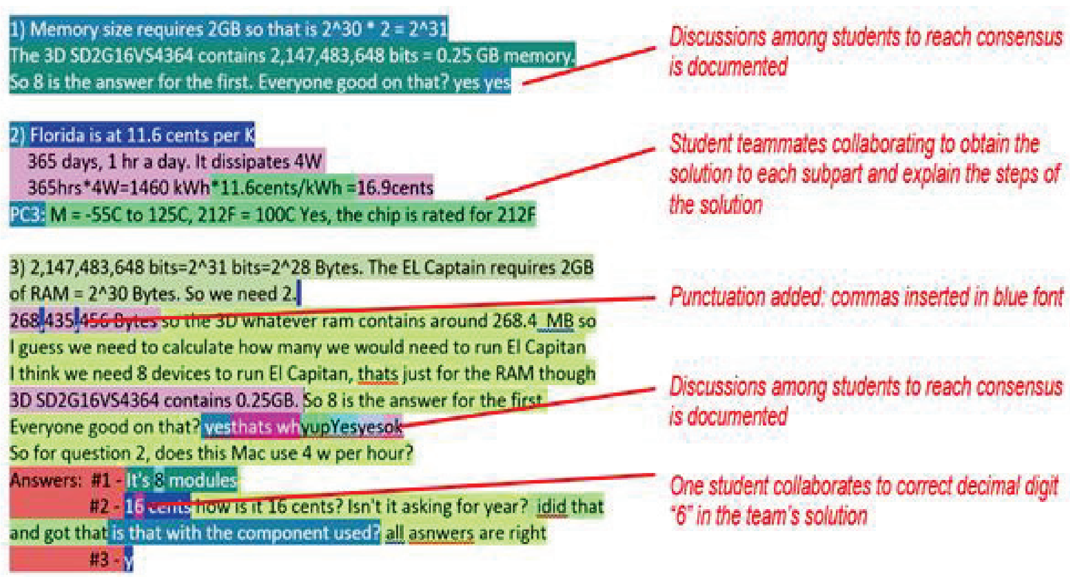


Figure 5: Collaborative Learning by Virtual Student Design Teams on an Etherpad Whiteboard (DeMara, Salehi, Hartshorne, & Chen, 2017).

Although GLASS has proven successful in mechanical engineering and computer engineering curricula, a potential limitation is its completely random composition of its student groups, which such research is addressed explicitly within Track 2 of this document. A further desirable characteristic for student-facing interfaces that is critical in the smartphone era is mobile-device support and friendliness. Selected DMTL platforms such as Collabrify have already embraced and demonstrated efficacy in the K–12 space. The challenge that remains is to devise an interface which unifies strengths across all of these platforms and is still cost-efficient, technically reliable, and easy to use.

Dede's team developed several generations of fielded inquiry-based DMTL frameworks that have been utilized successfully at the K–12 level. An example is the EcoMUVE Pond platform (Dede, Grotzer, Kamarainen, & Metcalf, 2017) shown in Figure 6. In this interface, students visit the pond over a virtual span of time, using their avatars to explore and collect data, with the goal of understanding changes and interdependencies within the ecosystem. The interface allows students to interact with virtual agents, chat with each other, and log their observations. Such an interface may also be extended using XR. As inspired by all of these current-generation DMTL frameworks, Table 3 summarizes potential research directions on this topic, which is congruent with the three dimensions of DMTL defined by Hmelo-Silver (Hmelo-Silver, Jeong, Faulkner, & Hartley, 2017).

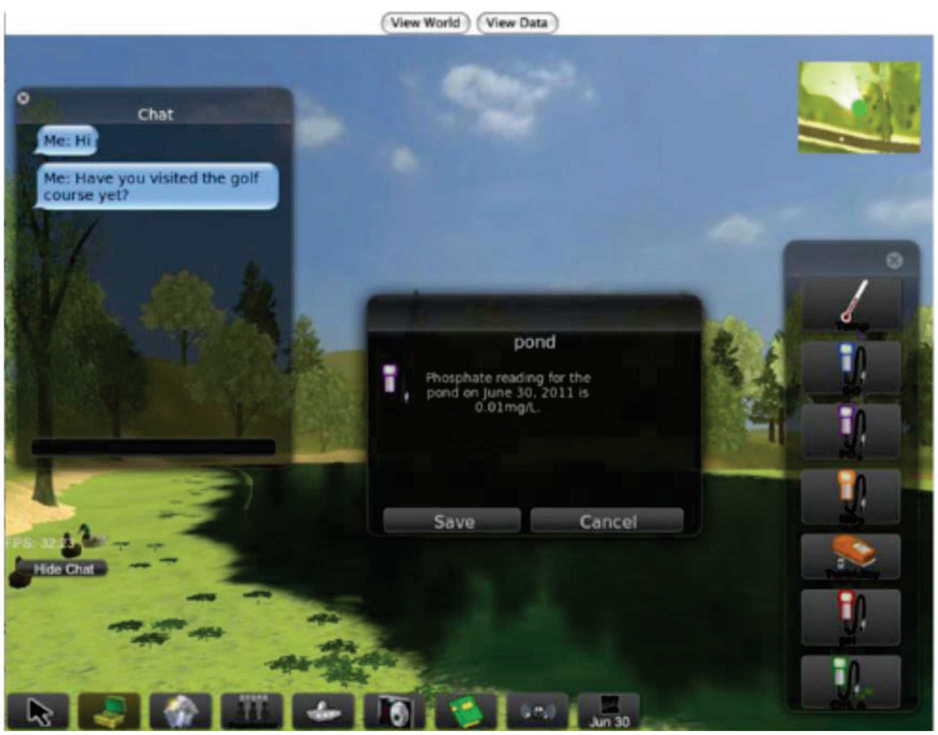


Figure 6: EcoMUVE platform for team learning in a virtual environment (Dede, Grotzer, Kamarainen, & Metcalf, 2017).

In the CLUE System developed by Concord Consortium (Edson, Bieda, Dorsey, Kimball, & Phillips, 2019), the emphasis is on a progressive widely known Scratch projects (Zuckerman et al., 2009) that allow users to develop and share digital artifacts like graphics and music, which respond to user-programmed behavior. Similarly, CLUE allows a workspace for middle school math students to organize and map their ideas through digital artifacts while receiving input from their classmates and sharing their own work with others. Students are encouraged to begin on exposure of student work. Figure 7 depicts the user interface provided by CLUE that follows various systems for co-construction, such as their own, then share with progressively widening groups (1 to 4 to the whole class) in their classroom. The same interface that allows them to share and create collaborative work on an individual exercise is also used to draw ideas from the problem statement, solutions to other problems, and their own previous learning log ideas.

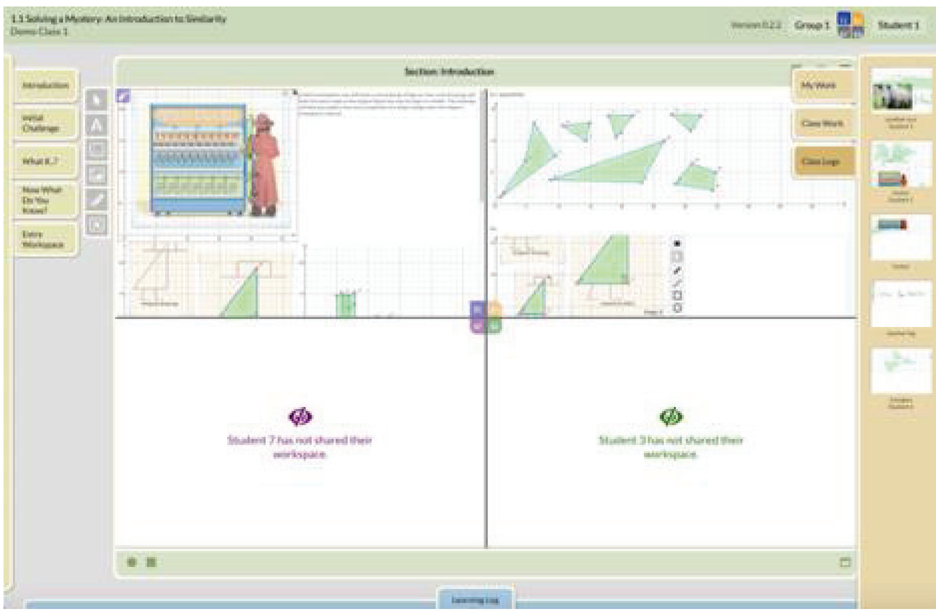


Figure 7: Reuse and bootstrapping from groupmates/teammates and the original problem content creates an egalitarian view of content in which the student's own work is seen as equal to their peers (Edson, Bieda, Dorsey, Kimball, & Phillips, 2019).

Mechanisms for teams to manage their performance is another element of student facing interfaces in DMTL. An example from InteDashboard™ following a team readiness assurance test (TRAT) used in TBL shows two mechanisms. The first is a team report which shows teams how they performed on the TRAT to help them self-assess areas where the team still needs clarification (Figure 8). Once the team has identified areas for clarification, teams can submit a clarification request to instructors (Figure 9).

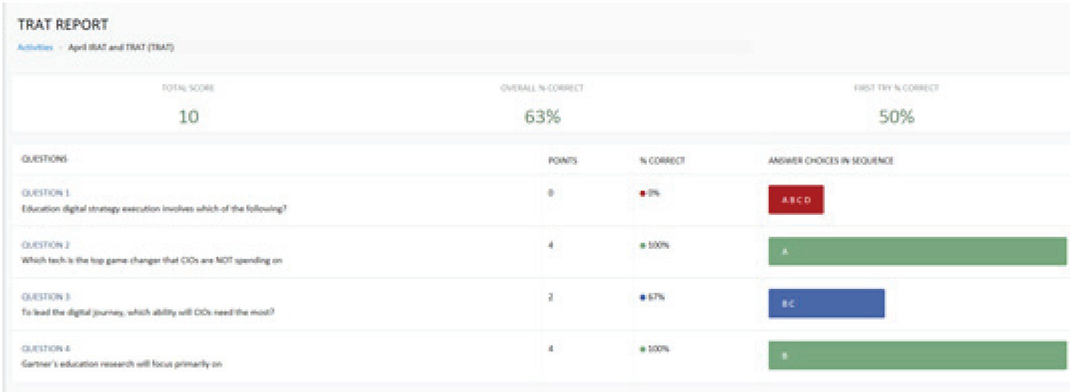


Figure 8: Example of an InteDashboard™ TRAT report.

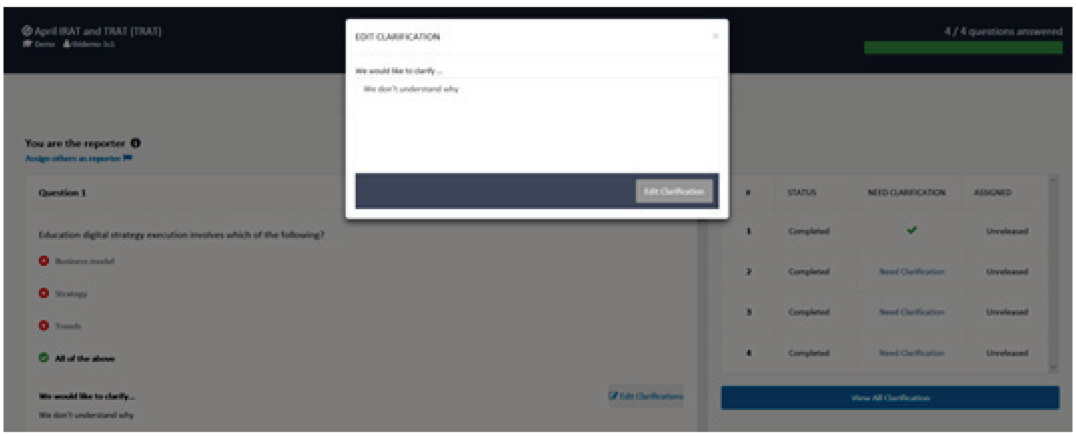


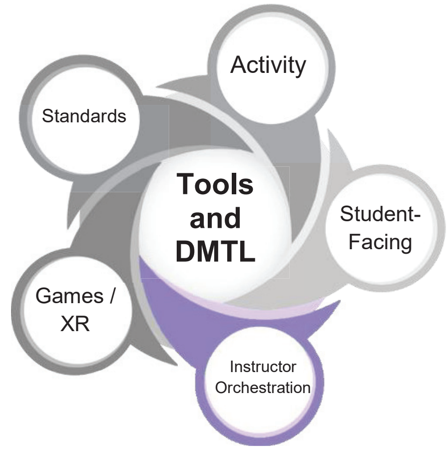
Figure 9: Example of Clarification Request feature in InteDashboard™.

Table 3

Research Opportunities to Advance Student-Facing Delivery of DMTL

Dimension	1-Year Research	3-Year Research	5+ Year Research
Collaboration Strategies	• Delineate attributes that students find important and valuable in team learning tools, e.g., via focus groups, surveys. • Collect and unify existing research evidence on how efficacy of student-facing capabilities vary according to delivery modality (including students that are physically co-located, in the same room but sitting separately, and not co-located) to inform impact of strategies in DMTL.	• Define standardized palettes of student-facing widgets for DMTL to determine the essential tools necessary to incorporate into the learning activity into specific K–20 curricula or cross-discipline activities. • Create and refine prototypes providing the above for browser-based, mobile device enabled, and XR-based platforms	• Research methods for semi-autonomous AI-enabled de-identification of video / observational raw data information as part of analysis including best practices related to privacy in collaborative learning toolsets.
Delivery Processes	• Investigate policies for role assignment and rotation within teams, exploration of how these policies should be adapted based on properties of tasks and distribution of the learners' characteristics within teams.	• Research methods to design more effective and affable peer evaluation strategies for DMTL. • Research user interfaces for learner feedback on performance in DMTL activities, e.g., ratings versus rubrics versus dividing points, etc.	• Conduct research on video analysis, capture platforms, and eye tracking for instrumenting and observing collaborative learning. Include pathways for automation of configuration, operation, and report generation from these systems.

Theme 1C: Instructor Orchestration and Assessment Tools



Theme Editors: Leslie Bondaryk, Ronald F. DeMara, Leilah Lyons, Brian O'Dwyer, Elliot Soloway, and Jody K. Takemoto

Research to advance the instructor-facing delivery of DMTL involves aspects of the orchestration of the activity as well as its assessment:

- How should instructor-facing user interfaces for DMTL operate and which features would be provided, including parameters which should be specified such as the number of teams, activity timer, and sub-goals?
- How to support instructor observability/moderation/facilitation of individual teams and the overall activity, and what are "operator loading limits" to do so (i.e., consider limited number of instructors and teaching assistants)?
- What features are critical for action review? For instance, are playback and freeze modes of session activities beneficial to team learning in STEM?
- How to provide both team-based and student-resolution scoring as well as feedback?
- Which are feasible solutions to automate scoring and the mechanisms necessary to implement within current and future LMSs?
- What would constitute real-time dashboard display content versus static summary report content?
- How to determine correctness, time-on-task, and identification of "pioneer teams" (i.e., first team to successfully complete a task) automatically?
- How to annotate/organize/provide feedback on submissions?

In the design of instructor-facing technologies for DMTL, a key design principle is supporting instructor observability/moderation/facilitation of individual teams and the overall activity within the classroom. Ideally, instructors would be informed of learner progress made during the activity in real-time, with more detailed data available for review after the activity. Implementation of real-time monitoring systems has received considerable attention in recent years, including works by Currey et al. (2019), Dillenbourg, Matuk, and Tissenbaum (2016), O'Dwyer (2018), and DeMara, Chen, et al. (2017), which emphasize real-time observability of student participation. Challenges that need to be addressed in such systems include determining necessary data to be captured, meaningful data presentation to the instructor, and efficacy of platform incorporation into the lesson plan. Although performance data has traditionally attained a primary focus, Dowell, Poquet, and Brooks (2018) proposed a metric for analyzing group communications and thereby determining participants' roles within a group, and the influence of these roles on student and group performance. A large body of research also exists on leveraging technology for developing effective formative and summative assessments for students, including work by Feng (2006) who developed the ASSISTment system for automatic data analysis of student assessments. The degree of automation that should be incorporated into assessment evaluation remains an open question suitable for ongoing research.

Within the community, there is consensus regarding the need to be able to view team progress at a high level before diving into details—a watchlist-style feature allowing to search and/or alert capabilities for various characteristics (e.g., which teams have the most/least interaction), which would also be desirable in an ideal interface. However, research is needed to both define appropriate indicators from learner observations, as well as delivery in a suitable interface for the instructor. In addition, the system should have a feature that allows student–instructor communication without being obtrusive to collaborative activity. Finally, the interface should have automated grading capability, with both aggregate and individual student data readily available to the instructor. In particular, an open research question is how to scale-up assessment for high enrollment courses which have become increasingly prevalent at many institutions in recent years.

Current widely-used platforms designed for team learning with one or more of these features in an instructor-facing dashboard include InteDashboard™, Socrative, Etherpad, and Perusall, an active reading-centered collaborative platform (Miller, Lukoff, King, & Mazur, 2018). Although these interfaces aim at improving the impact and efficiency of the instructor, several pedagogical challenges remain which must be addressed. For one, most LMS's accommodate a team-wide submission that lack student-resolution. Moreover, even the most assistive DMTL instructor interfaces which support auto-grading of assessments do not provide any remedial feedback and therefore are limited in their potential with respect to learning outcomes. Furthermore, regardless of the analytics provided, whenever an instructor interacts individually with a certain team, he/she is unable to watch analytics pertaining to other teams. Thus, there is an open research question regarding the provision of dashboard-style mechanisms that allow the instructor to "catch up" without being constantly overwhelmed with data. Considering that the instructor may not always have the ability to go to a desktop computer to review dashboards, mobile support would be an advantage here. An intriguing research possibility is to integrate such dashboard features into a smartphone/tablet-based display to realize a highly-effective mechanism for instructor orchestration of DMTL to direct and guide the instructor while navigating from team to team within large collaborative learning spaces.

To illustrate recent instructor-facing DMTL interfaces and associated assessment capabilities, the GLASS framework provides a representative example. During DMTL activities using GLASS, individual student design team members submits discretized responses as highlighted in the Response Tabulator section of Figure 4. Critically, responses are structured for partial credit, as well as auto-grading and grade book tabulation. "Sample response formats include multiple choice having a single correct response which are structured for incremental solution, multiple answer format having multiple subparts which must be selected for full credit, or a numeric value within some specified tolerance, usually +/– 5%" (DeMara, Salehi, et al., 2017, p. 12967).

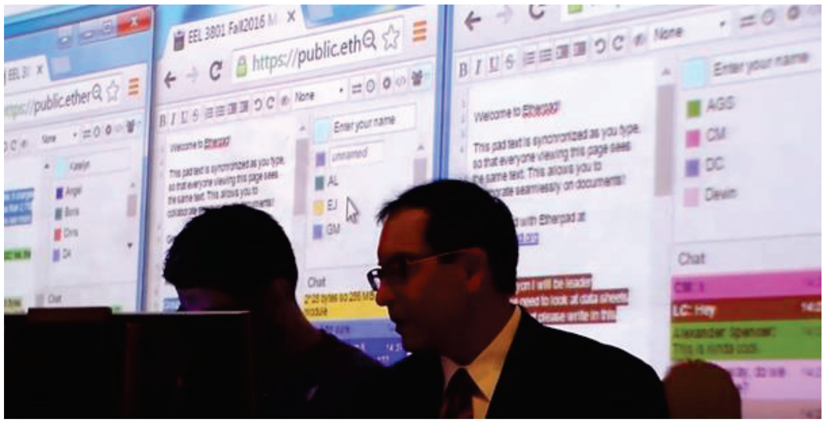


Figure 10: Design team windows projected on auditorium screen during observation and guidance by Instructor / GTA.

Meanwhile, as shown in Figure 10, "the instructor observes both the auto-graded scores from the Response Tabulator as well as the whiteboard windows, of each design team. At the University of Central Florida (UCF), the Canvas LMS is utilized and provides a Moderate Quiz feature, which displays the scores of submissions as they occur in real-time, thus allowing the instructor to monitor progress and more closely examine the details of submissions. This assists the instructor in identifying progress and misconceptions as they are occurring, even for large enrollment sections, as well as to identify the Pioneer Group, which is the first group to submit a completely correct response" (DeMara, Salehi, et al., 2017, p. 12968).

An intriguing feature provided by GLASS is to allow the instructor to either privately view the collaborative digital whiteboards of each design team, or display the design team work environment to the entire class. Similar interfaces to facilitate orchestration of the learning activities have been deployed in the CLUE system at the Concord Consortium within the context of informal STEM learning (Edson et al., 2019). For instance, Figure 10 also shows the instructor and GTA interacting with a team via their chat platform to provide real-time, individualized guidance, which can be done systematically for all teams. Thus, GLASS increases the efficiency and effectiveness of instructional staff, refocusing primary pedagogical activities from instructor-centered (i.e., lecture) to student-centered (i.e., observation and guided learning). Utilization of a selected Pioneer Group extends the benefits of the learning environment beyond knowledge acquisition via the development of technical soft-skills as the Pioneer Group presents and defends their design to other design teams in the class. Further, GLASS provides instructors with a more comprehensive view of the solution processes and level of understanding of each team, allowing for targeted guidance and traceability of learner interactions, both of which provide valuable feedback for refining the pedagogical approaches and pace for the course content, as well as opportunities to provide more individualized instructional settings (DeMara, Salehi, et al., 2017).

Another example of a DMTL instructor tool is InteDashboard™ which has been used for team-based learning classes. Several components that faculty have found useful include a dashboard of team responses during the team-readiness assurance test (as Figure 11 shows). In this assessment, teams complete a multiple choice test and receive immediate feedback after each attempt. Faculty have valued seeing how teams are responding in real-time to hone in on troublesome spots (in the example below, Question 4) and have insight into what teams are thinking (in this case, most teams were thinking B or D initially). Furthermore, the real-time nature of the display provides an indication of progress as well as the ability for faculty to identify teams that might be progressing more slowly than others. This use of this display would indicate:

1. Data on how the class is progressing as a whole
2. Data on the relative pace of team progress
3. Data on which items were potential trouble spots
4. Data on why particular items might be trouble spots

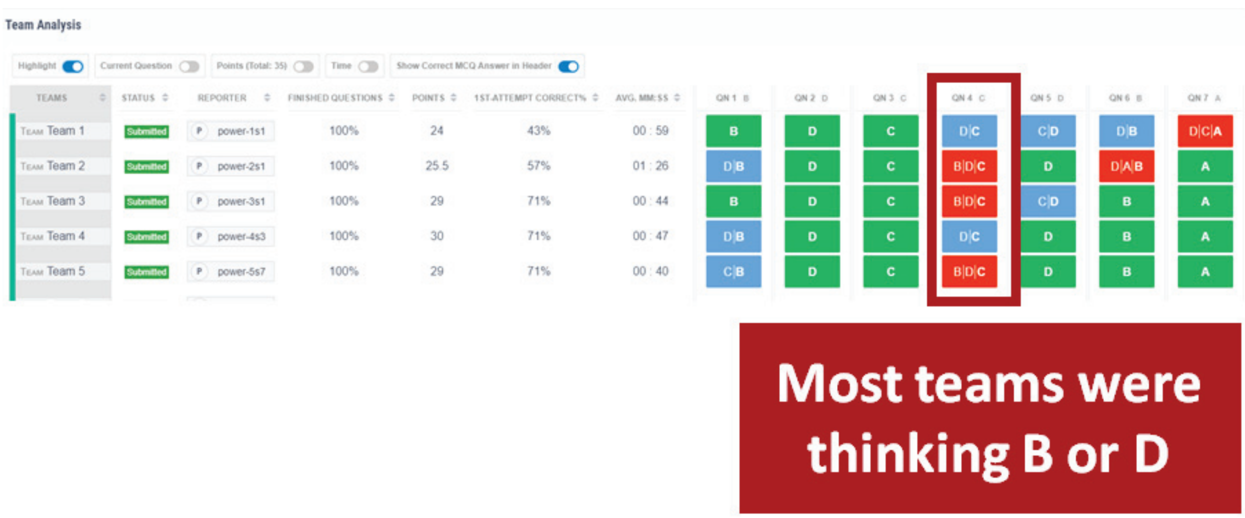


Figure 11: InteDashboard™ real-time team analysis tool.

Another use of InteDashboard™ in TBL classes is to support the facilitation of case discussions (through the interface depicted in Figure 12). Instructors have utilized several elements including:

1. Visual display of which teams had selected which answer
2. Mouse-over capability to access additional information such as the names of students on a particular team or the rationale a team provided for an answer
3. Duration of case for classroom time management

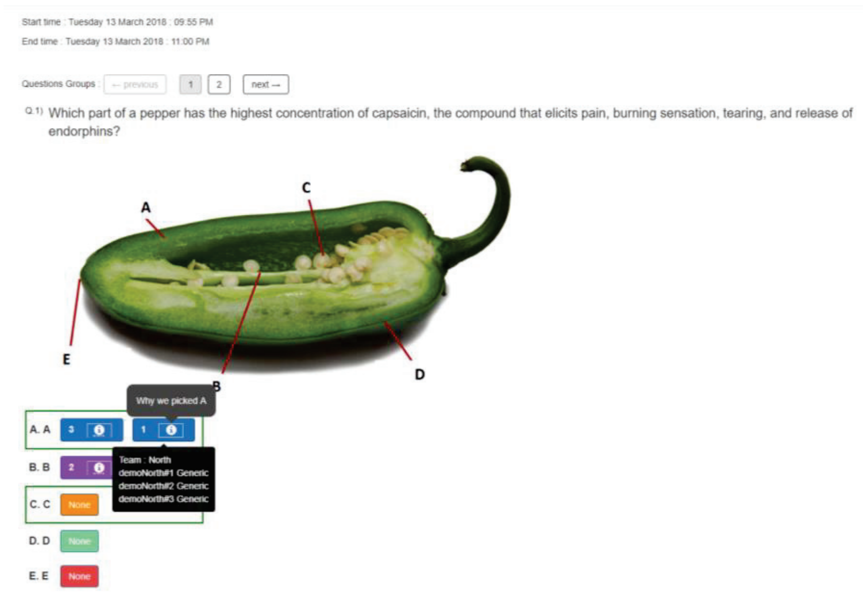


Figure 12: InteDashboard™ case discussion tool.

At the K–12 level especially, instructor-facing interfaces would need to provide analytics regarding both adherence to expectations (i.e., which teams are on task, while also providing data on strengths/weaknesses of teams and which can be drilled-down to assess and assist individual students). Finally, an additional challenge to such an interface would be determination of data collection protocols when student teams are working outside of class. This constitutes a challenging but high payoff extension for the use of DMTL in massive open online course (MOOC) settings.

Teacher interfaces that longitudinally track student conceptual growth of cross-cutting ideas generated over time and over multiple units of content are prudent. Mechanisms must be developed to assist both the learner and the instructor in tracking progress through the domain and as a collaborator. Machine learning techniques should be developed to assist the instructor in recommending and providing extended exercises, either for remediation or challenge, and in helping them focus attention on those groups that require it. Instructor interfaces should likewise enable class-wide summarization in real time, and provide individual-, group-, and class-level "just-in-time" digital supports and commentary.

Based on this discussion, Table 4 gives future research directions towards advancing the state-of-the-art in instructor-facing dashboards.

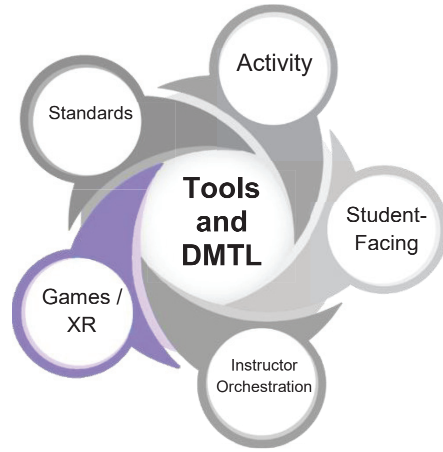
Table 4

Research Opportunities for Advancing Instructor Orchestration and Assessment Tools

Dimension	1-Year Research	3-Year Research	5+ Year Research
Collaboration Strategies	• Conduct a workshop to determine consensus on essential assessment measures that will identify effective collaborative learning that are feasible in current DMTL frameworks.	• Investigate means by which DMTL can help to reconcile: • (a) the analysis and characterization of situational phenomena (so-called microscope view) with the analysis and characterization of longer-scale trajectories (so-called telescope view) • (b) individual-level analyses with group-level analyses?	• Design intelligent tools to generate collaboration-oriented student progress reporting, e.g., collaboration report cards. • How can we employ machine learning and other AI-driven techniques to better characterize the processes of collaboration from artifacts/data that can be observed?
Delivery Processes	• Conduct a multi-institutional survey to delineate key components and dimensions of an instructor dashboard for DMTL frameworks. Research considerations include: What are the human factors or design elements that make them easy for faculty to learn and use? What is the relevant or useful information for instructors?	• Conduct interdisciplinary research to advance the transitioning of DMTL orchestration from guidance, to feedback, to mirroring (for support of self and social regulation). Research considerations include: How to move through these phases? What are best practices in each phase, including student regulation and instructor support?	• Design, utilize, and refine new assessments that can capture the longitudinal growth of learners in collaborative settings, respond to students' diverse interests and expertise, and discover their strengths that they can build on. This can address the research considerations of how to not only identify their gaps/deficits but also to actively support the needs of each learner.
Technology-Driven Advancements	• Research the automation of assessment for DMTL in STEM curricula. First-year research could standardize methods for automation of	• Design dashboards / interactive agents to provide simple integrated analytics/feedback based on teacher demands and student	• Initiate long-term research on AI-assisted orchestration of learning teams. Research considerations include:

	scoring and feedback, enabling longitudinal student assessment in a particular topic area. • Continue on-going research on video analysis, capture platforms and eye tracking for instrumenting and observing collaborative learning, but with an increased emphasis on its linkage to instructor orchestration of DMTL activities in STEM classrooms.	needs in real-time. A key research question is how automation can focus on critical aspects of the work the instructor should prioritize to address the needs of effective DMTL within specific phases, contexts, and modalities of learning.	• a) How can machine learning approaches assist instructors to maximize learning outcomes in collaborative environments? • b) How XR and AI be combined in DMTL settings to realize new instructor-facing applications to replay, evaluate, and refine collaborative learning activities. • c) Approaches to realize software platforms that help teachers learn/adapt their skills in DMTL settings, besides those of the learners themselves.

Theme 1D: Educational Games / XR



Theme Editors: Leanne Coyne, Wendy Howard, Leilah Lyons, and Jody K. Takemoto

Educational Games / XR constitute an end-use of DMTL of their own, as well as a potential contributor of constituent approaches and technologies crosscutting other use-cases of DMTL. Research considerations include:

- Which attributes of educational games relate most closely to DMTL, including elements in common, and how do these compare/contrast?
- Which progress achievement and features of educational games can be most useful to apply for learner teams in the STEM classroom?
- What is the role of XR in conducting DMTL activities in the near and long term?
- What would be archetypal "best application" of games/XR for DMTL?

Gamification can best be understood as the integration of gaming elements into traditionally non-game context. Gaming elements such as conflict (i.e., between players, human or otherwise), problem solving/goal obtaining, storylines, and rewards (i.e., points, badges, money), are often integrated to foster increased task enjoyment, engagement, and performance (Cardador, Northcraft, & Whicker, 2017). Theoretical underpinnings for the effectiveness of learning through gamification can in part be explained by operant conditioning (Skinner 1938), constructivist theory (Piaget, 1953; Vygotsky, 1978), motivational theory (Graham & Weiner, 1996), and self-determination theory (Ryan & Deci, 2000).

Educational games have been traditionally used in K–12 for fostering student engagement. Recently, there has been increasing emphasis on expanding the scope of educational games to the higher education realm as well, particularly in the context of extended reality (XR), an umbrella term encompassing virtual reality (VR), mixed reality (MR), and augmented reality (AR). Mallavarapu (2019) has been a pioneer in this area, with the virtual museum exhibit, "Connected Worlds," offering what is described as "ludic engagement" whereby visitors are engaged more deeply with content by receiving access to visualizations of data skimmed from their use of the exhibit.

Participants discussed the advantages of XR in the context of DMTL, including its ability to demonstrate difficult concepts. Future research could focus on enabling team learning settings infeasible within classroom and informal settings which provide opportunities to practice and demonstrate skills while receiving formative feedback from their endeavors, just as simulations have been used to educate the workforce and military personnel for training purposes for many years.

Current state-of-the-art educational games supporting DMTL comprises quizzing products such as Kahoot! (Dellos, 2015), Socrative (Awedh, Mueen, Zafar, & Manzoor, 2015), Quizlet (Wolff, 2016), and also simulation-based games offered by the Concord Consortium (Mutch-Jones, Gasca, Pallant, & Lee, 2018) and PhET simulations hosted by the University of Colorado, Boulder (Wieman, Adams, Loeblein, & Perkins, 2010). Thus far, these products have been incorporated primarily into K–12 settings. In higher education, games/competitions between students in classroom settings include the "beer game," a classic group learning activity in undergraduate management courses such that students collaboratively form solutions to managing a profitable supply chain to meet the customer demand (Kaminsky & Simchi-Levi, 1998). Furthermore, simulation-based activities, such as virtual labs, have been gaining popularity in higher education as a solution to issues such as scalability and feasibility limitations of a traditional lab; with the advent of XR, this trend could easily grow to encompass DMTL. A recurring tension during workshop discussions spanned the possibilities such as using massively-multiplayer online role-playing games such as MMORPG and Rumii as edugames and using story/simulation/narratives to build engagement, as well as within fields having attributes related to STEM, such as pharmacy education (Coyne, Merritt, Parmentier, Sharpton, & Takemoto, 2019).

STEM-focused educational games currently available in XR, such as HoloLab Champions by Schell Games (Cooper & Thong, 2018) and Number Hunt (PaleBlue XYZ, 2018), are primarily single-player games. However, single-player XR games can be adapted for team learning by enabling one student to wear a headset while the other team members provide guidance. An excellent example of this model is Keep Talking and Nobody Explodes, by Steel Crate Games (Kane, Fetter, & Pestaluky, 2015), a game that emphasizes communication. This game involves one player attempting to dismantle a bomb in XR, while non-XR players provide bomb defusal instructions. Multiplayer educational games where all players work together or competitively in XR are yet to be developed, highlighting an opportunity for research.

While logistic challenges include training instructors on new technologies/platforms, research needs span devising more efficient methods of incorporating proper scaffolding for students, achieving cost effectiveness suitable for student use, and the effort required to develop XR scenarios as a platform for distance team-based learning (Coyne, Takemoto, Parmentier, Merritt, & Sharpton, 2019). On the other hand, the potential for DMTL-driven games to significantly boost motivation and allow role playing in clearly-defined STEM design team roles is vast and compelling. Specific research directions are summarized in Table 5.

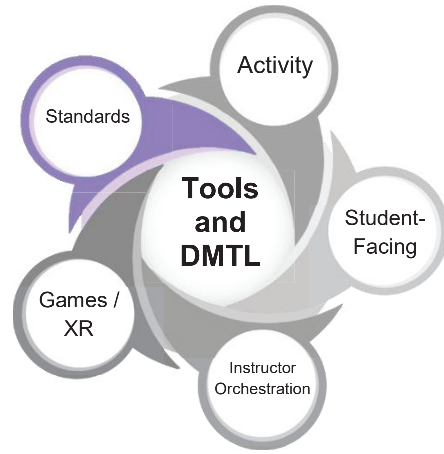
Table 5

Research Opportunities Relating to Educational Games / XR in DMTL

Dimension	1-Year Research	3-Year Research	5+ Year Research
Collaboration Strategies	• Convene experts to reach consensus on a taxonomy of the most effective strategies used within current-generation educational games at supporting collaboration.	• Innovate new means to design DMTL activities that will engage multiple roles or skills distribution to encourage collaboration that scaffolds both social/soft-skills along with the acquisition of content knowledge.	• Study the benefit of games and collaborative simulations to advance building of skills associated with proficiency in collaboration. • Explore how DMTL-based adaptive games can be used to help bestow learners practice with alternative collaboration patterns and escape low-gain routine interpersonal interactions.
Delivery Processes	• Survey literature to identify which pedagogies were most prevalent and effective within games to support teams and discover the reasons why.	• Investigate role of game-style strategies as a mechanism to explore, guide, and/or reinforce the students' roles as learners on teams. • Explore how to use game-based techniques to keep team member roles clear and learners motivated	• Develop and assess responsive/adaptive games (i.e., games that change based on student decisions) and research ways in which XR can augment these goals (team collaboration, time to pass the gavel, and means to engage lurkers). • Research the feasibility and motivation benefits to the potential of "whole curriculum gamification" whereby graduation criteria are gamified via perpetual DMTL activity spanning years of enrollment. Which programs could benefit from such a DMTL approach to STEM learning?

Technology-Driven Advancements	• Convene a workshop to identify which games have STEM instructors found to be effective, including differentiation by discipline, age, and educational setting.	• Conduct research to develop and refine the kinds of design elements that are critical for an immersive (VR or game-like) environment to emphasize interdependency and the integration of diverse talents or competencies distributed among learners.	• Apply and extend AI technologies to: • Longitudinally suggest team learning activity that is adapted to the skills and needs of learners. • Adapt the XR environment to increase learning including auto-insertion of virtual students with teams, possibly triggered by stagnation of progress or retreading the same ground.

Theme 1E: Standards and Clearinghouses



Theme Editors: Leslie Bondaryk, Ronald F. DeMara, Mohsen Dorodchi, Wendy Howard, Leilah Lyons, and Jody K. Takemoto

Research in Standards and Clearinghouses for DMTL spans
open questions:

- What types of open standards development or synthesis workshops
  can advance the community, which is highly interdisciplinary and utilizes specific terminology and perspectives, to collaborate on the definition of transportable formats for DMTL content?
- How can format standards help to interchange activity content, results, and studies to refine the learning activity content narrowly and DMTL techniques broadly?
- Who can and should host Clearinghouses for problem banks: what, where, when?

A key challenge that is currently facing DMTL is the lack of standardized lesson plans, learner concept maps, and scaffolding for students who will be evolving as collaborative learners. Nor do we have robust technology standards and taxonomies for incorporation of these materials into existing systems, such as rostering. Therefore, fundamental research is needed on how to design transportable DMTL-based curricula and their associated assessments. Standardization of portable elements that lead to successful and efficient collaborative teams, and general characteristics of such teams, as well as an understanding of common target integration platforms is essential to achieve widespread roll out and popularization of DMTL. Research in this field has been performed by Wen (2017), Fiore (2003), Sottilare (2018), and Graesser (2018), which complement Tuckman's previously-published stages of team development (Tuckman,1965) . Tuckman's team development model is challenged by Gersick's punctuated equilibrium model of group development which suggests that "teams progress in a pattern of 'punctuated equilibrium,' through alternating inertial change and revolution in the behaviors and themes through which they approach their work" (Gersick, 1991, p. 13). This idea is supported by several subsequent studies (Basoglu, Fuller, & Valacich, 2012; Jasperson, Carter, & Zmud, 2005; Koh & Lim, 2012; Maznevski & Chudoba, 2000). Standardized clearinghouses for problem banks are necessary to maintain assessment integrity. A standard understanding of issues will allow for determination of preferable mechanisms and interfaces needed for effective LMS integration of DMTL. Research areas in this endeavor are summarized in Table 6.

It will be critical to the uptake of digital collaboration tools that they are gracefully integrated into common LMSs, MOOCs, and informal science learning platforms that currently exist for creating rosters and assigning activities to the members of those rosters. Mechanisms for creating groups and reporting on both the group and the individual as appropriate must communicate with the system or they are unlikely to have impact. For instance, clearinghouses for geospatial data inventory and access have proven effective in geosciences (Nebert, 2000). Research can explore extensions to service-oriented architecture approaches that utilize object brokers with mediation services to allow indexing and retrieval of related DMTL activities across multiple STEM disciplines (Nativi, Bigagli, Mazzetti, Boldrini, & Papeschi, 2009).

Currently, the IMS Global Learning Consortium has been attempting to bridge and standardize the broad variety of single-learner tools in an effort to make them more adoptable (IMS, 2019). IMS resources have attained widespread usage in K–12 education to deliver lesson plans. Research is needed to organize a similar extended set of taxonomy, interface, and pattern definition exercises, similar in character to those undertaken by the W3C, to create an easier method of incorporating both student and teacher tools. This is particularly critical for K–12, where the funding to adopt new technologies is scarce and core systems are seldom refreshed. Specific research directions are listed in Table 6.

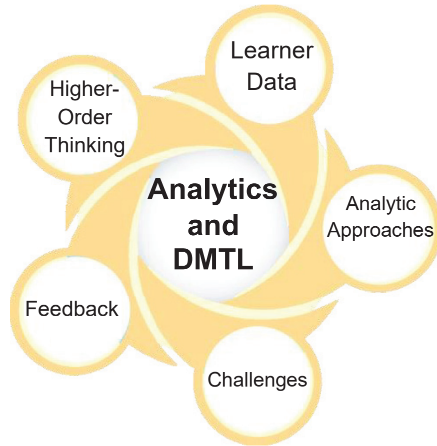
Table 6

Research Opportunities to Advance DMTL Standards and Clearinghouses

Dimension	1-Year Research	3-Year Research	5+ Year Research
Collaboration Strategies	• Convene a workshop to coalesce data collection and DMTL standards as to what is done already for related educational interchange similar to DMTL that can be adapted.	• Create and adapt technologies for building deep knowledge creation through big data collection of DMTL activities.	• Research the feasibility of data-mining the fielded DMTL use-cases and lesson plans to automatically infer new standards and formats to increase efficacy of delivery, data collection, and reporting.
Delivery Processes	• NSF may advance survey collection instruments from DMTL participants, open to community for contribution via a Web repository to form a scoreboard that facilitates more useful comparison/contrast across domains, disciplines, and grade	• Research the optimization of DMTL environments and practices: what is the optimal team size, random versus criteria-based? • Leverage cognitive science research on team behaviors to distill down into a compact form that faculty can use to put	• Develop and validate tools to rapidly optimize DMTL specific learning environments at scale.

	levels to gain new insights on cooperative learning.	DMTL into practice in their classroom.	
Technology-Driven Advancements	• Support the creation of a learning community crowdsourced repository of existing real-time online learning (among other educational tools) for assessing solutions available. Research questions include how to provide mechanisms for the inventory, search, and retrieval of different DMTL environments, practices, lesson plans, and reusable activities: definitions of terms, team sizes, random teams versus criteria-based, teams changed each week versus same teams for a semester, time of team activity, level of team activity, synchronous / asynchronous, physically co-located or distributed.	• Advance DMTL approaches that are standardized or interoperable so more accurate and extensive A/B testing of DMTL innovations can be performed. • Organize and orchestrate a standards initiative in partnership with existing technology interface organizations to produce specifications that allow easy reuse.	• Design interfaces accounting for new approaches to data collection, management, and analytics, and different types of discourse/collaboration tools that support students' in situ participation. •

Chapter 4



Track 2: Personalizing Collaborative

Introduction

Selecting, organizing, and adjusting team members to promote full-engagement and learning by all members is a critical aspect of team learning. Yet, the current research base does not sufficiently inform nor automate the formation of groups to optimize learning and to promote personalized collaboration. The scope of this track focused on the types of data, use of analytics to guide team formation and organization, considerations around group learning versus collaborative learning, using data to provide feedback, and using data to enhance the cognitive demand in team learning. Data and analytics across varying contexts of team learning became the focus of the track discussions including team dynamics, data sets, analytic approaches, and challenges in contexts such as learning STEM in K–12 classrooms, learning STEM in informal (out of school) settings, learning in higher education, and learning in professional settings (e.g., industry, emergency response teams, military, and so forth). Consensus in the community indicated that studies and practices should consider common features of data and analytics across the contexts, as well as some discretely different needs and tools in specific contexts. In other words, consensus in the community is that some aspects of personalizing collaborative learning are context specific, while others have broader generalizable aspects that could apply across varying contexts.

Consensus in the community centered mostly around data and analytics related to personalization and collaboration. Data was considered in terms of five broad categories of foci: (a) individual learning (skills and knowledge), (b) team cognition (shared cognition), (c) productivity (completing tasks—individuals and teams), (d) social interaction and discourse (communication) within and across teams, and (e) personalization. Analytics were considered in terms of time (length of time to gather, analyze, report, and use), data source, and intended purpose.

The goals and objectives of team learning have been refined for this paper to include:

1. Develop students into better team members
2. Learning of content knowledge, mastery of skills or building efficient high performing teams
3. Learning about teams and team learning
4. Supporting diversity, equality, and inclusiveness in teams

This theme encompasses consideration of how to lower barriers for:

1. Data collection in multiple environments and at various time scales (real-time neurotransmission through to K–16 and beyond)
2. Connection of data across different measurement resolutions and sources
3. Unification of data from different sources into a common format and reducing logistical, legal, and ethical barriers for accessing data
4. Data cleansing and validation
5. Researchers to form effective multi-disciplinary teams to study team learning
6. For practitioners to adopt and implement data analysis in implementing team-based learning
7. For continuous implementation of team-based learning from kindergarten through higher education, and in both formal and informal learning environments
8. Formative assessment for learners and instructors—seeing how they are performing in regards to a goal or trajectory

This theme was further organized into five core sub-themes as illustrated in Figure 13:

2A: Types of learner data

2B: Assessment mechanics (analytic approaches for literally noisy data)

2C: Challenges for optimization of team learning

2D: Using data to provide feedback (to instructor and/or students)

2E: Enhancing cognitive demand and mastery of learning outcomes via analytics

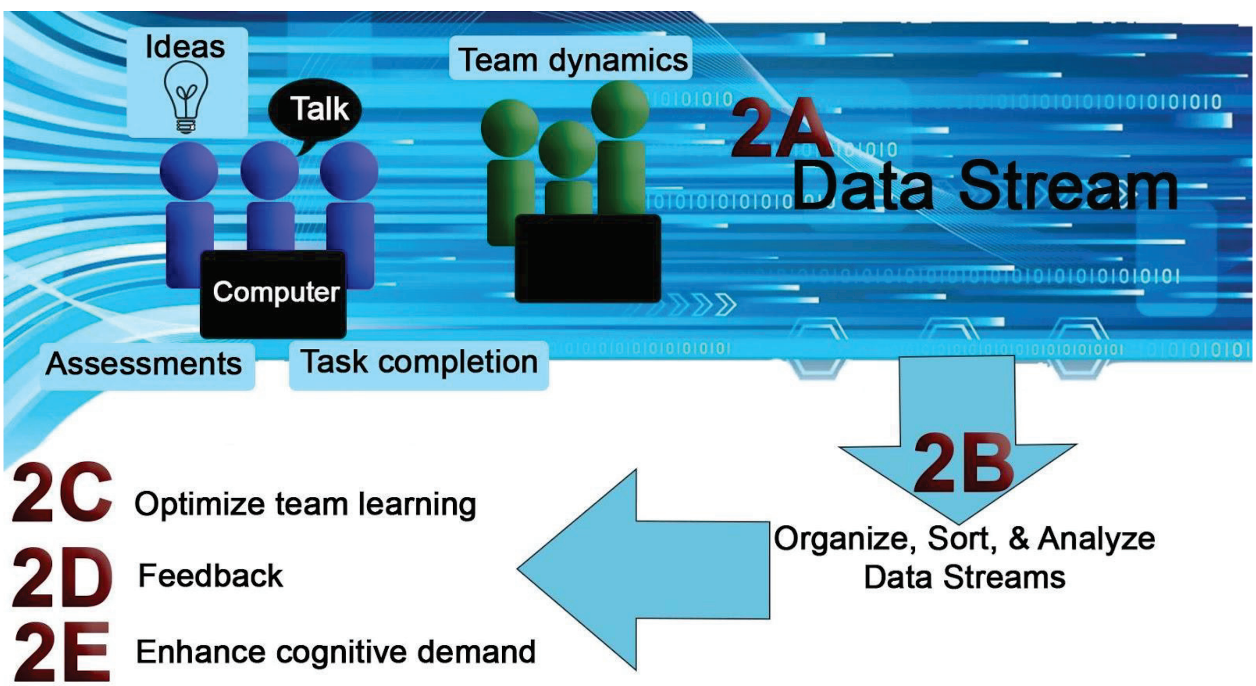
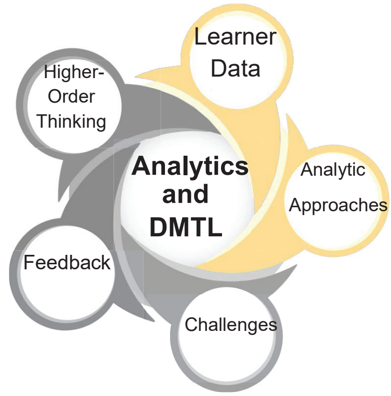


Figure 13. DMTL components and relation to Track 2's Themes.

Theme 2A: Types of Learner Data and Theme 2B: Assessment Mechanics



Theme Editors: Samuel Spiegel, Jennifer Tsan, and Dezhi Wu

In today's classrooms and technology landscape, there are
vast and varied ways of gathering different data from different sources. For example, we can now trace proximity of team members, follow eye movement, gather team member perceptions, record data on emotional state of the team members, and in some studies even collect brain wave and activity functions (Salas et al., 2015). The challenge and "state of the art" for utilizing data to personalize collaborative learning is in explicitly knowing what you want the teams to accomplish, what you want to examine, and why (purpose and use).

While emerging studies may come out of existing data sets, new data should be gathered and analyzed with explicit and intentional purposes defined. Data overload and/or not having the right data to inform your question or to better understand team learning has been a challenge noted by most of the participants in the session. This can be better managed by having clear research questions and/or a clear vision of what you are trying to understand. What problems are you seeking to understand or fix? What insights do you want to gain toward assessing student performance and learning? What are the intended learning outcomes? The context also makes a difference. For example, are students creating a product or studying an established concept? Is the setting a traditional four-year university classroom, an online course, or part of a workplace training?

The context, research question, problem being addressed, and available resources as a whole should drive and inform the data to be collected. Given these caveats, there are some data gathering and analysis techniques that are providing new insights into DMTL. The field is widening in terms of what and how team interactions are being studied, and how these can then be used to personalize team learning.

For instance, at the Colorado School of Mines, students study the design and enactment of learning experiences using the framework of Engineering Learning (). Engineering Learning guides instructors to explicitly define clear learning outcomes, and then to align the learning activities, learner organization (e.g., working individually or in teams), and assessments directly back to those learning outcomes. The design of the course is studied by gathering and analyzing course artifacts such as the syllabus, assessment tasks, lesson plans (when available), and instructor reflection notes. The enactment is studied by reviewing samples of student work (e.g., products produced through team work, student reflection logs) and through observation of the classes. The observation utilizes an online tool called the Engineering Learning Classroom

Observation Tool (ELCOT; Sanders, Spiegel, & Sherer, 2018; see Figure 14). Using ELCOT, the observer records what is happening in the classroom in real time at two-minute intervals through a Web browser on a laptop computer. The observer selects fields on a Web-based interface to note how students are organized.

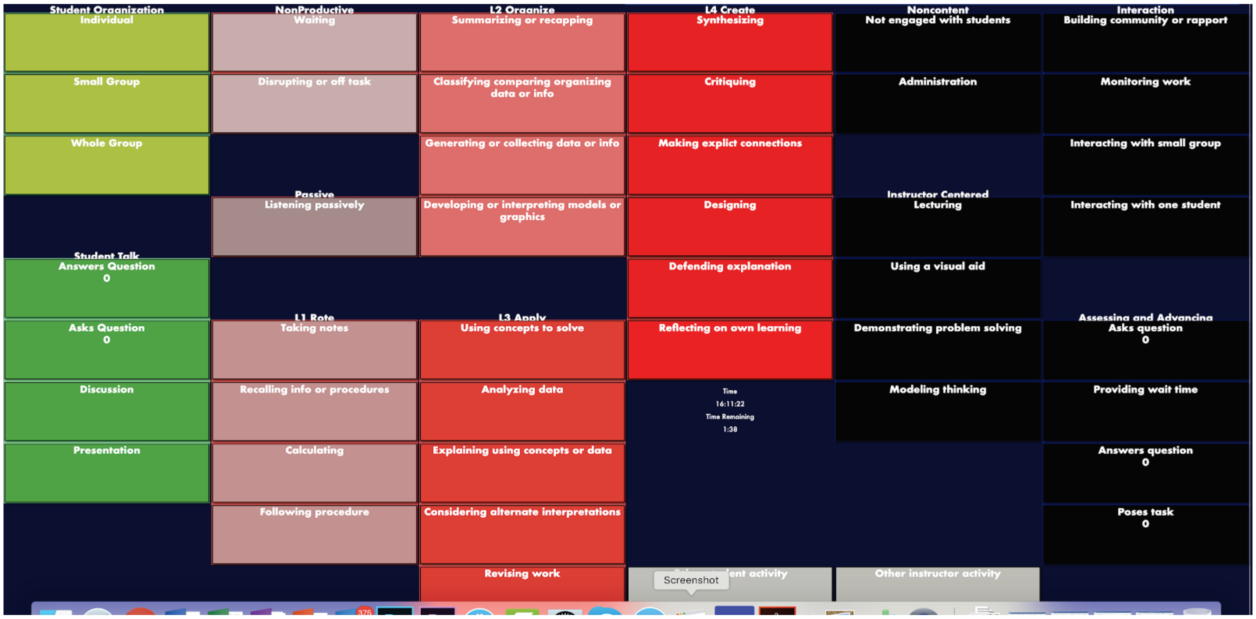


Figure 14: ELCOT user interface.

(i.e., individually, small group, whole group); when students ask questions (quantity and type of questions are recorded); what students are doing along with the level of cognitive load (Webb, 1997); and what the instructor is doing such as modeling expert thinking, lecturing, or monitoring students. ELCOT provides a broad look at the ways classrooms and student interactions are organized, and considers how well that aligns with the desired learning outcomes.

Other groups are looking at multimodal analysis of team interactions (Dale, Fusaroli, Duran, & Richardson, 2013; Richardson et al., 2005), while others are focusing on varying aspects of team dynamics such as emotions (Reidsma, Heylen, & Ordelman, 2006), intrapersonal and interpersonal interactions related to task complexity (Ramenzoni et al., 2011), socialization of intelligence (Resnick, 2017), neurodynamic organization (Stevens & Galloway, 2017), and communication analysis through computational linguistics (Dowell, Nixon, & Graesser, 2018). Others are looking at the interactions of multiple teams, such as emergency responder teams that consist of firefighters, police, medical, and other expert teams coordinating to respond to an emergency (Bannan, Gallagher, & Lewis, 2017; Steinke, et al., 2015; Zaccaro, & Fletcher, 2017). This data can be difficult and expensive to collect. There is also the problem of being able to parse this data quickly enough to intervene in real time.

Video capture and analysis is growing in popularity in studying team learning through epistemic network analysis (ENA). ENA is a technique in quantitative ethnography that uses visualization and statistical methods to identify meaningful patterns in discourse. ENA is a methodology grounded in epistemic frames theory, which posits that "learning can be characterized by the structure of connections that students make among elements of authentic practice" (Shaffer & Ruis, 2017, p. 182). ENA operationalizes this theoretical approach by modeling the connections between salient constructs in the data, particularly by examining the co-occurrences of codes within conversations (Shaffer, 2017).

Spatial, time, and cultural data are also being used to facilitate and assess team learning. Cultural analysis is exploring cultural formative assessments that build on students' pre-existing interests, identities, and knowledge (Penuel & Van Horne, 2016). The cultural aspects can both influence the interactions and ways of working together in teams, as well as inform what is viewed as successful in team learning (Ruvalcaba, Werner, & Denner, 2016). Others have been able to use proximity detectors and related approaches to examine interaction geography data as a means to understanding how learners coordinate with one another spatially (see Shapiro, Halls, & Owen, 2017).

Therefore, the data sources being studied range from instantaneous measures of neuroactivity (e.g., microscopic assessment of individual brain activity and learning) up through enormous repositories of granular data that can be analyzed to look at team patterns across large groups (e.g., huge data sets that look at interactions and learning over extended time).

In regards to platforms that facilitate optimal formation of teams, CATME (Loughry, Ohland, & Woehr, 2014) was one example of a platform used by varying institutions to plan and coordinate team formations. Newer models are being explored (e.g., Fathian, Saei-Shahi, & Makui, 2017). However, each model relies on different frameworks and perspectives of team learning. Further research is warranted in the design of tools to help construct, organize, and monitor teamwork.

The driving factors in data selection and analysis should be the learning outcomes, task design, and contextual considerations. For instance, in one learning sequence designed to teach students about the sun, earth, and moon interactions to explain the phenomena of the phases of the moon, students are organized into homogenous groups based on misconceptions they hold about phases of the moon. The activity is designed to scaffold the learning from where each team is beginning and advances everyone's learning to meet or exceed the desired learning outcomes. In this instance, the data used to organize the groups is a writing task where students are asked to write and/or draw (with labels) on a 3"×5" card (thereby limiting responses to quick answers) what causes the phases of the moon as we see them from earth. The responses are then quickly sorted by the instructor into one of eight categories based on expressed misconceptions. For example, some students will indicate that they have no idea, while others might indicate that clouds cause the phases, that it is the Earth's shadow that causes the phases, and so forth. This design was possible due to research conducted around common misconceptions in science and engineering (Driver et al., 1994). Each group is given a different question to explore that will cause them to challenge their personal beliefs about the system. Other outcomes and tasks might be better served by organizing students into heterogeneous groups, based on their content knowledge, experiences, gender, or a myriad of other factors. This requires complex modeling and design to align the best group formation with the desired outcomes. It will also require more research into the formation of different groups in association with the desired outcomes and task design.

Challenges

Measuring and modeling the dynamic phenomena of team learning remains a challenge. The complexity of individual and group dynamics, cognition, performance, and learning is difficult to model. Research groups are making progress in using AI to better understand, model, and simulate group interactions (Rose, 2018). One such group is the Discussion Affordances for Natural Collaborative Exchange (DANCE).

Another challenge is the state of available and affordable technology. A large amount of research in DMTL, particularly with co-located students, focuses on dialogue and eye-tracking. Unfortunately, the technology for speech-to-text is still very limited and does not work well in noisy classrooms, with young children, or with many regional accents. Additionally, eye-tracking equipment can be expensive to purchase and time-consuming to set up. Moreover, the typical eye tracking technology is not designed for teams but individual users, so it is challenging to capture team dynamics using eye tracking methods to accommodate multiple learners simultaneously if they are co-located. The cost of using this stream of eye movement data for teams would be much higher assuming the technical setup is appropriate.

Other challenges lie in the category of data management. What are the best ways to manage the collection and storage of different data types (e.g., speech, biometrics)? This is true at the individual instructor level, institutional levels, and cross-institution levels. One recommendation from the group is to explore a national database on team learning that would allow researchers from multiple fields and institutions to share and utilize datasets. This will require both technical solutions (e.g., how to securely store and share the data) as well as solutions to multidisciplinary collaboration (e.g., using common nomenclature to allow easier cross referencing).

Data and privacy concerns are also a challenge. Navigating the boundaries between the Family Educational Rights and Privacy Act of 1974, instructional enhancement data, and other institutional, state, and federal policies can be confusing and serve as a barrier for some researchers. One question that emerged several times is whether students' data should ever be erased and, if so, what are the conditions to trigger the removal of the student data? Table 7 summarizes specific research directions.

Table 7

Research Opportunities to Advance Use of Data to Enhance Team Learning

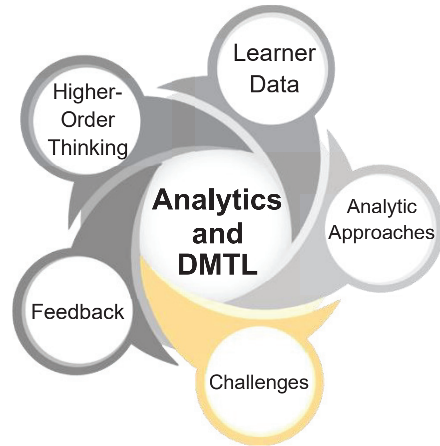
Dimension	1-Year Research	3-Year Research	5+ Year Research
Data and analytics to select and organize groups	• Develop venues and platforms/repositories (e.g., data sharing portals) that facilitate cross-disciplines (convergent research approach) and cross-setting studies of the formation of teams. For example, reducing the barriers between research in medical, industry, military, informal, K–12, and higher-education settings around DMTL. • Develop a glossary and more clearly define data, theories, and research questions and approaches to facilitate cross-disciplinary conversations and meta-studies.	• Research projects to more clearly identify how technologies can and should be used to organize and support team learning. In other words, what tools exist that can help to both organize the teams as well as scaffold learners to do more advanced work. • Research to develop tools that facilitate and accelerate the collection, analysis, and useful reporting of varying data sets that inform DMTL (e.g., discourse data, video, biometrics, organizational patterns, etc.).	• Conduct studies to explore how different formations of teams best match to intended learning outcomes and lesson(s) design. For instance, are there outcomes that are best achieved by homogeneously or heterogeneously organized teams? Categories of homogeneity include factors such as gender, prior-knowledge, skills, and interests. • Explore how different formations of teams best match to mode of interactions (i.e., co-located teams, virtual teams including regional geographic locations or across global locations, hybrid interactions). • Develop a database of data and analyses to facilitate meta-studies to better understand the impact of different team formations based on individual characteristics, learning outcomes, curricula design, and learning context.

Analyzing, reporting, and using data while teams work (embracing and tackling the complexity and dynamic nature of team learning)	• Build a relational database of pedagogies, tools, data collection, and analytics on Authoring Tools for DMTL (e.g., an integrated database that could be navigated easily and made accessible to the community via website). • Develop standards for research and data reporting regarding DMTL (i.e., tackling ethical considerations, privacy concerns, terminology across disciplines, and sharing/multiple researcher use of the data). • Expand research efforts on how to use cognitive and cultural data to inform the design of learning environments (e.g., Bell, Stromholt, Neill, & Shaw, 2017). •	• Develop tools to automate or accelerate the collection, analysis, and reporting of individual and team cognition and interactions so that the data can be used in real-time to inform DMTL. • Refine observation tools for face-to-face interactions that can guide team learning in real time or close to real time; and consider comparable ways to assess team interactions in online interactions. • Study the variety of possible data sets produced by Internet-enabled devices (e.g., sensors, personal watches, video, eye tracking) to develop protocols that are appropriate for varying settings considering privacy, access, costs, and value of the data sets to inform DMTL.	• Study the incorporation of AI and machine learning as part of the "team" in team learning (e.g., robot and human teams, simulated peers/coaches that are machine-based to both facilitate and enhance human learning and performance). • Identify patterns that indicate stress points in DMTL, which could be used to formatively assess and adjust instruction (e.g., using ENA [epistemic network analysis] to identify productive vs. destructive patterns of communication and interactions). • Develop measurements and modeling tools to enhance situation awareness, coordination, learning and performance across multiple teams (e.g., first responder teams—fire and rescue, medical, police, dispatch, etc.).
Data and analytics to evaluate individual and team learning and performance	• Develop criteria for what counts or is important to evaluate in terms of individual and team learning (part of this definition might require explicit definition of what we mean by "learning"). • Develop protocols for accessing and aligning different data sources. This should tackle the lack of transparency in	• Continue to refine protocols for accessing and aligning different data sources, including security and privacy protocols (e.g., when should a student's records be erased? Can/should a student be forgotten?). • Develop tools to facilitate accessing and	• Design new data analysis methods (data science approaches) to better study and evaluate DMTL. Many of the traditional methods for clean small-scale data sets won't work with large-scale messy data. This poses challenges to traditional educational researchers and practitioners.

	how others share data, as well as concerns about equity (who can afford to access the data).	aligning varying data sets.	• Study approaches to DMTL that focus on learning rather than performance, allowing students and teams safe opportunities to struggle and fail as part of the learning process.

Theme 2C: Challenges for Optimization of Team Learning

Theme Editors: Samuel Spiegel, Jennifer Tsan, and Jessica Vandenberg



In this paper, group and team learning are differentiated based on the goal and coordination of the effort. Group learning is what occurs when two or more individuals discuss and consider a topic, knowledge, or skill together for the purpose of each member better understanding the topic, knowledge, or skill. Team learning is based on the organization of the team, where all members have a common goal to accomplish. In order to accomplish the goal, team members must learn how to work together, share relevant information and skills development, and take on differing roles to achieve the goal. Unless there is an explicit effort to establish and monitor common learning goals for all individuals within a team, it is likely that team learning can lead to different individual learning outcomes. Defining clear and measurable learning outcomes for individuals and the team is a core aspect in optimizing team learning. You need to know where the individuals and team need to get to (i.e., learn) in order to guide and assess their progress. In some settings the focus may be more around the team performance and less on learning outcomes, but that should be aligned with the intended learning outcomes.

One approach being developed to optimize team learning, referred to as Automated Peer Learning Cohorts (Auto-PLC), is based on the hypothesis that assessment data for individual learners can be useful in grouping learners into more effective and efficient peer learning cohorts (DeMara, Turgut, Nassiff, Bacanli, & Bidoki, 2018). As depicted in Figure 15, AutoPLC incorporates analytics from formative assessments to advance team learning. First, use of autograded digitized formative assessments reallocates instructor and teaching assistant workloads from lower-gain instructional activities, such as grading, to higher-gain learning activities, such as targeted remediation and mentoring. Second, following the review of formative assessments, students are afforded remedial opportunities. To facilitate this process, Auto-PLC's statistical clustering routines are applied to the auto-graded results of formative assessments to allow for partitioning of learners into focused peer learning cohorts consisting of members with complementary knowledge gaps and skill efficacies. (DeMara, Turgut, Nassiff, Bacanli, & Bidoki, 2018). The learner cohorts were constructed automatically via chi-squared test clustering analysis using the formative assessment results which have been accumulated to-date in the course. Using the skill matrix scores of the students, the chi-squared method was used to compare students where the chi-squared distance gave a number to assess the similarity of two students. Auto-PLC selected the student whose skill score was the most distant. The farthest skill score student was iteratively put through the same process until a group of four was formed. This further scales to large enrollments, typical with introductory STEM courses, by affording learners opportunities to participate in complementary peer mentoring. (DeMara, Turgut, Nassiff, Bacanli, & Bidoki, 2018).

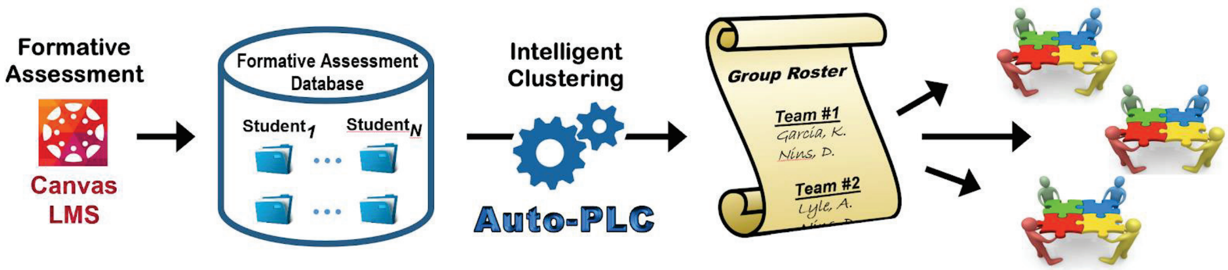


Figure 15: Intelligent Clustering of Peer Learning Cohorts by mining digitized formative assessments already on-hand from the lecture component (DeMara, Turgut, Nassiff, Bacanli, & Bidoki, 2018).

Another approach to team grouping builds on the work of semantic and linguistic analysis. Group Communication Analysis (GCA), an automated methodology for linguistic analysis investigates communication between online learners. Learner's interactions over time (e.g. "participation, internal cohesion, responsivity, social impact, newness, and communication density") are explored sequentially through computational means (Dowell, Nixon & Graesser, 2018). The resulting information provides a structure for understanding the group dynamics including intra- and interpersonal group communication. GCA employs a multidimensional and robust methodologies to uncover more than the quantity of words spoken in a group. GCA extends what is known about a group and how a group functions.

Statistical Discourse Analysis (SDA) is another methodology that is growing in use in studying teams. It models significant moments that can alter the pattern of subsequent behaviors, the effects that earlier behaviors have on important or target outcomes, and influences at different levels (Chiu, 2008). SDA has been used to explore how pivotal moments like conflict or idea breakthroughs change discourse patterns, how behaviors like asking questions or verbalizing confusion may lead to the outcome being studied, and how individuals influence the group over time (Chiu & Lehmann-Willenbrock, 2016; Molenaar & Chiu, 2014).

Challenges

Group learning has different indicators, purposes, and definitions across the varying disciplinary groups. For the purposes of this conference and paper, group learning is defined to be the changes in shared cognition, skills, and interactions that occur in group dynamics. Learning at the individual, component-team, cross-team, and multi-team levels were taken into consideration regarding team learning. There is consensus that within team learning you can have individuals that learn at different paces, and may or may not learn the same content and skills; so identifying and differentiating between individual and team learning is an aspect that needs to be further explored. Consensus in the community is that there are differences in how collaborative learning, group learning, team learning, and parallel-individual learning are used in the literature; but no clear vision has emerged for defining these differently or marking them as similar enough to consider them, for practical purposes, the same. This is one of the areas we identified as needing further study to facilitate cross-disciplinary discussions and research. Specific research directions are outlined in Table 8.

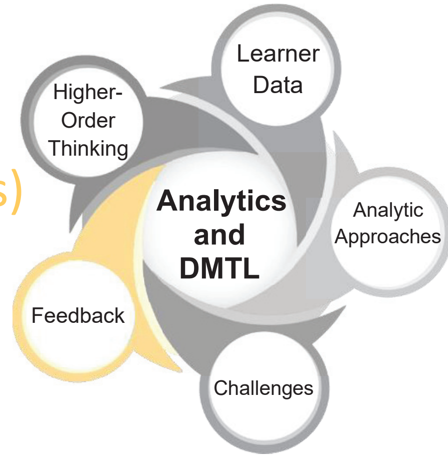
Table 8

Research Opportunities to Advance Optimization of Team Learning

Dimension	**1-Year Research**	**3-Year Research**	**5+ Year Research**
Defining and understanding the goals and purposes of team learning	• Conduct a rigorous literature review toward defining purposes and goals of team learning across varying settings (K–12, higher education, industry, military, etc.). • Develop a glossary and more clearly define data, theories, and research questions and approaches to facilitate cross-disciplinary conversations and meta-studies.	• Research to develop tools that facilitate and accelerate the collection, analysis, and useful reporting of varying data sets that inform decisions to utilize and/or organize team learning opportunities. Research projects to more clearly identify when team learning is necessary or the best approach to use. • Research to develop tools that facilitate and accelerate the collection, analysis, and useful reporting of varying data sets that inform decisions to utilize and/or organize team learning opportunities.	• Conduct studies to explore how different formations of teams best match to intended goals and context. • Further analysis and development of tools that facilitate and accelerate the collection, analysis, and useful reporting of varying data sets that inform decisions to utilize and/or organize team learning opportunities.

Analyzing, reporting, and using data while teams work (embracing and tackling the complexity and dynamic nature of team learning)	• Better define what is meant by "optimization" in team learning. Is it related to team dynamics, individual learning, overall performance of the team, and so forth? • Examine the impact of assigning roles and other team-based practices on optimization of the team learning.	• Consider how the context and goal(s) influence the optimization of team learning. For instance, does data from teams working in mob programing help inform team learning for business courses or first responder teams? • Study ways to most efficiently establish and maintain team norms, group interactions, and tasks.	• What are best practices in task and group designs to optimize team learning? • Develop platforms or tools that allow the analysis and reporting of varying and large data sets in real time to inform decisions while the team is learning. • Determine best practices for utilizing unobtrusive sensor-based and audio/video digital data streams to improve our understanding of team and multi-team behavior, coordination, and learning, including visualization of the data to uncover meaningful indicators to optimize learning.

Theme 2D: Using Data to Provide Feedback (to Instructor and/or Students)



Theme Editors: Mohsen Dorodchi, Leilah Lyons, Michael Spector, and Samuel Spiegel

Providing feedback based on formative assessment is critical to learning (Ambrose et al., 2010; Maki & Kuh, 2017). Yet, given the growth of available data, the diversity of learners, and evolving domains and learning outcomes, it is not clear what data should be used, how it should be structured and delivered as feedback, nor how digital media can best be utilized to provide efficient and effective feedback. For instance, how is providing peer feedback perceived and accomplished? Is peer feedback seen as an important task that is both useful to the provider and the receiver, or is it just viewed as another task to complete by the provider?
One technique called Dynamic Enhanced Evaluation of Problem Solving (DEEP) involves asking students to answer four questions about a problem situation: (a) what are the key factors influencing this problem situation?, (b) how would you briefly describe each of those factors?, (c) how are the factors related?, and (d) how would you briefly describe each of those relationships? That leads to an annotated causal influence diagram or concept map that can be compared to a reference model. The differences can then be used to prompt a learner to consider something not included in the initial representation (Spector, 2008).

Another project, Tandem (Derry, 2019), is a robust application for improving student engagement in teamwork-related activities. Tandem uses the implementation of surveys provided at regular intervals, personalized feedback for each learner, and teamwork lessons as tools to support improved collaborative skills and experiences. His Web application provides features for both student groups and instructional teams. Data from the integrated tools is visible via team and learner dashboard, and can be further enhanced through the integration of a digital coaching tool, ECoach, which provides personalized teaching and learning support mechanisms.

Finally, another approach is using wearable Internet of Things (IoT) devices such as proximity sensors for analyzing the efficacy of multi-team systems in real-time for purposes of either immediate feedback or post-hoc remediation (Dubrow et al., 2017).

Challenges for this theme:

Our ability to provide rapid and effective feedback during team training depends on how well we can make sense of the parallel and complex information streams that are increasingly being generated about the team, team members, and the environment. An additional challenge in this regard is trying to avoid information and cognitive overload for the learner and the instructor by endeavoring to best organize and present salient information at the right time, visualized in an intuitive way.

Another core challenge is centered on trustworthiness and usefulness of feedback. When someone generates and/or receives feedback, how can they best assess its relevance, accuracy, and usefulness? Training instructors and learners on how to efficiently and effectively generate feedback, as well as how to effectively receive and utilize that feedback, is an area of growth for our communities. The role of AI and machine learning in providing feedback is another area that warrants further exploration. Developing standards, tools, and resources to help guide, develop, and assess human and machine feedback will further advance team learning. Table 9 gives specific research directions.

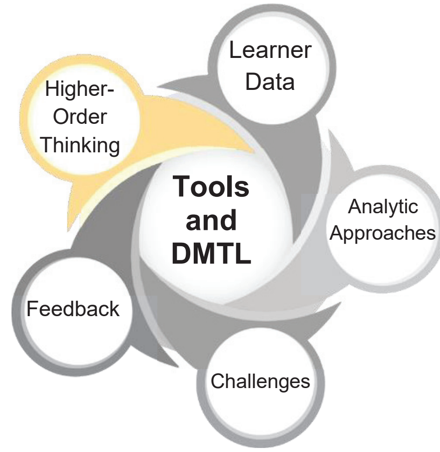
Table 9

Research Opportunities to Advance Use of Data to Provide Feedback

Dimension	**1-Year Research**	**3-Year Research**	**5+ Year Research**
Defining best practices with existing tools and infrastructure	• Conduct a rigorous literature review to consider best practices in who gives feedback and in what format (e.g., peer vs. instructor feedback, written vs. oral feedback, etc.). • Explore mobile apps and online tools used to facilitate feedback and minimize distractions and "off task" behaviors.	• Research projects to identify techniques that can be used to automate productive feedback so it can be offered more immediately. • Identify best practices in how mobile apps can be used to provide timely and meaningful feedback to learners.	• Conduct studies to consider aligning feedback with intended outcomes and learner context modality (e.g., gamification of the learning tasks, online discussions, video analysis and feedback, etc.). • Further analysis and development of tools that facilitate and accelerate feedback across varying dimensions of team learning such as process (learning, interactivity), productivity (task completion, ideation), behavior, etc.

Analyzing, reporting, and using data while teams work (embracing and tackling the complexity and dynamic nature of team learning)	• What can peer feedback accurately provide to the receiver of the feedback? • Examine the impact of assigning roles and other team-based practices on optimization of the team learning.	• How might providing peer feedback in team learning scenarios facilitate both individual and team learning? • How can we best formatively assess individual and team learning to guide the learner (peer and/or instructor feedback) and help them identify and address their own barriers to learning (self-feedback)?	• What are best practices in task and group designs to optimize team learning? • Develop platforms or tools that allow the analysis and reporting of varying and large data sets in real time to inform decisions while the team is learning. • Determine best practices for utilizing unobtrusive sensor-based and audio/video digital data streams to improve our understanding of team and multi-team behavior, coordination, and learning, including visualization of the data to uncover meaningful indicators to optimize learning.

Theme 2E: Enhancing Cognitive Demand and Mastery of Learning Outcomes via Analytics



Theme Editors: Samuel Spiegel, Jessica Vandenberg, and Dezhi Wu

Modern life and work require more advanced ways of thinking and dealing with vast amounts of information and data. Our ability and the mechanisms to access information have changed, and there are implications for how we solve problems. However, as technology has changed, the way in which we solve problems has also changed. Today, many approach problems by spending less time in upfront formalized "research" and more time in trial-and-error and high-risk approaches. This necessitates focusing learning on higher cognitive demand levels (Francis, 2016). The added complexity and difficulty of tasks with higher cognitive demands lends itself to improved team learning outcomes (e.g. as long as the level of cognitive demand is a "stretch" but not a chasm, with respect to students' present level of expertise and ability) (Hamar et al., 2016).

Developing data access and analysis protocols, tools, and technologies that allow real-time feedback to both the learner and instructor can enhance the ways in which students can be assessed and then guided to master higher-level learning outcomes. A challenge is defining tasks that are cognitively demanding for both individuals within the team and for the combined team effort. Sometimes, the navigation of working in a team adds complexity, but not necessarily the complexity we intend or want students to focus on.

One approach to this challenge is cognitive load theory, which suggests techniques for presenting information in a way that optimizes intellectual performance of all learners—for example, by coding multiple information elements as one element to reduce cognitive load (Kirschner, 2002; Paas, Tuovinen, Tabbers, & Van Gerven, 2003). Other techniques include the use of AI (Murphy, 2019) and gamification of tasks (Osatuyi, Osatuyi, & De La Rosa, 2018) to scaffold learning.

Specific research directions are listed in Table 10.

Table 10

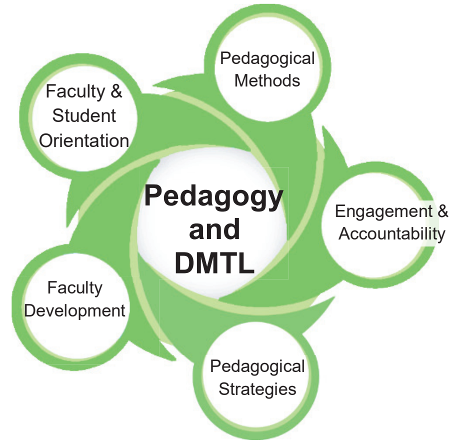
Research Opportunities to Enhance Cognitive Demand and Mastery of Learning Outcomes via Analytics

Dimension	1-Year Research	3-Year Research	5+ Year Research
Assessing and understanding cognitive demand	• Propose or host multi-disciplinary meetings supported by various societies to consider defining cognitive demand definitions that may be contextually based or learner based—is the same task the same cognitive load for each learner and in each context? • Develop a glossary and more clearly define assessment theories and approaches, and cognitive demand.	• Research projects that investigate data mining techniques on log data that have been successful for evaluating individual learning and pilot them on collaborative data to assess learning and cognitive demand levels.	• Improve on methods to automate coding/classification of discourse data and alignment with cognitive demand of the task.
Analyzing, reporting, and using data while teams work (embracing and tackling the complexity and dynamic nature of team learning)	• Better articulate observable patterns of different levels of cognitive demands in different settings. • Consider ways to more tightly align the cognitive demand of the learning outcome,	• Consider how cognitive demand should influence the design of the team learning. • Study ways to most efficiently establish scaffolds that support learner success without reducing cognitive demand.	• Analysis and development of tools that facilitate and accelerate the collection, analysis, and useful reporting of varying data sets that inform decisions regarding cognitive load and adjustments to the learning tasks.

	assessment, and learning task.		• Develop platforms or tools that allow the analysis and reporting of varying and large data sets in real-time to inform decisions while the team is learning.

Chapter 5

Track 3: Supporting Digital Teams Using Active Pedagogical Strategies



Introduction

Past research in STEM education has embraced numerous pedagogical benefits of collaborative learning environments, including increased learner engagement and improved learner satisfaction with STEM content areas and majors (Holland, Major, & Orvis, 2012; Michael, 2006; Prince, 2004). Collaborative learning environments extend opportunities for both knowledge acquisition and communicative experiences, as these facilitate deeper learning through the introduction of creative ideas and approaches via shared mental models and active participation in project- and problem-based instructional settings. These benefits and opportunities improve both knowledge acquisition and the development of communication skills (Duffy & Cunningham, 1996; Goggins, Jahnke, & Wulf, 2013). Additionally, more intensive teamwork and the development of soft skills can be enhanced through intentional peer, content, and instructor interactions that are supported via collaborative learning environments (Arnaud, 2013; Kuh, Pace, & Vesper, 1997). As a result, there is a likely enhancement in the development of critical thinking, problem solving, decision-making skills (Cortright, Collins, & DiCarlo, 2005; Walker, 2003), and learner engagement with STEM content (Johnson, Johnson, & Smith, 1998).

The focus of *Track 3: Supporting Digital Teams Using Active Pedagogical Strategies* was the exploration of pedagogical mechanisms to support, extend, and enhance settings that utilize digitally-mediated team and collaborative instructional approaches. The primary topics of *Track 3: Supporting Digital Teams Using Active Pedagogical Strategies* included the following:

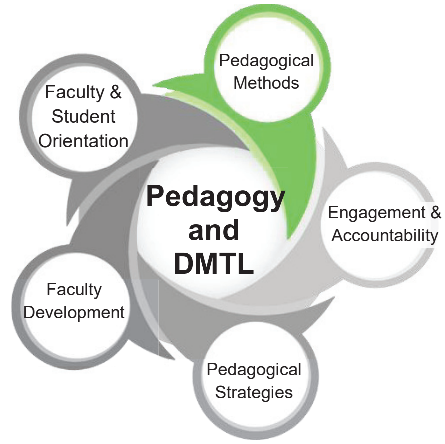
- Defining pedagogical strategies for technology-enhanced active learning to support synchronous and asynchronous student team and collaborative events;
- Underpinning the group and collaborative activities within STEM classroom settings via cognitive science, including peer interactions, intrinsic/extrinsic incentivization, and lurker/lone wolf interactions; and
- Exploring andragogical/pedagogical methods leading to autogradable/reusable/scalable problem

design, Individual/Team Readiness Assessment Tests (IRAT/TRAT), incentivization/assessment/accountability protocols, and actionable lesson plans.

Sample guiding questions for Track 3 included:

- What are key characteristics of effective pedagogical strategies that support engagement of all learners in digitally-mediated collaborative and team-based learning?
- What are critical tenets of pedagogical strategies that effectively minimize challenges typically associated with digitally-mediated collaborative and team-based learning?
- Which pedagogical “best practices” support accountability and assessment of the contributions/achievements of individual students when utilizing digitally-mediated collaborative and team-based learning?

Theme 3A: Pedagogical Methods for Team Management



Theme Editors: Richard Hartshorne, Hans Esteves, Jody K. Takemoto, and Kenneth C. Walsh

Introduction

In recent years, a relatively low percentage of young people have pursued STEM careers which, alongside the current aged population of engineers and scientists, has resulted in a continually diminishing STEM workforce pipeline (President's Council of Advisors on Science & Technology [PCAST], 2010, 2012). According to the 2012 PCAST, colleges across the nation ought to increase the number of graduates in STEM careers by one million over the next decade. Consequently, there has been an unprecedented emphasis on reforming STEM education in hopes of addressing the impending needs and the extended implications of establishing and disseminating research-based evidence for increasing interest and engagement in STEM education and careers. Additionally, as STEM fields and careers are becoming increasingly specialized, the ability to quickly acquire, manage, and communicate/share knowledge is becoming increasingly important for tomorrow's STEM workers.

Often seen as a major contributor to the decreased interest of American young people in pursuing STEM degree programs and careers, is the perceived lack of excitement and personal relevance attributed to STEM educational settings (Holmegaard, Madsen, & Ulriksen, 2014; Lace-Costigan, 2017; Palmer, Burke, & Aubusson, 2017; Prieto & Dugar, 2017). Indeed, considerable evidence has shown that actively engaging students yields greater levels of understanding and retention of content (DeHaan, 2005). Therefore, affording STEM learners with numerous and diverse collaborative, communicative, and problem-solving opportunities is becoming increasingly necessary, though often overlooked, in STEM (Vennix, den Brok, & Taconis, 2017; Engle & Conant, 2002; Fiore, Graesser, & Greiff, 2018). Further, the facilitation of such skills, and the utilization of associated learning environments and pedagogical approaches, are not typical of STEM instructional practices. Thus, revising STEM pedagogical approaches and transitioning from teacher-centered to student-centered, collaborative, active approaches may be an effective strategy to simultaneously address these issues (Mayer, 2009; Meltzer & Thornton, 2012).

Consideration of a number of factors associated with the integration of effective pedagogical methods to support team management include, but are not limited to: (a) maximizing the student role in team management and minimizing the instructor role, via pedagogical approaches; (b) determining the most effective pedagogical methodologies of support team management in both synchronous and asynchronous DMTL learning environments; and (c) assessing the impact of the role of group selection approaches, and resulting group dynamics, on team management strategies implemented.

In shifting from more teacher-centered team management to more student-centered team management, numerous social, cognitive, and task-related dynamics, alongside varied pedagogical considerations, must be addressed. Such issues include (a) group structure, (b) team roles, (c) establishing team norms, (d) task relevance, (e) communication, and (f) incentivization.

Group/Team Structure

For many students in STEM fields, collaborative learning in complex instructional settings is a new endeavor. Thus, simply putting students in groups and assigning a task is often a futile approach to integrating collaborative learning in an instructional setting. Adding further complexity is the integration of digital tools to support the collaborative learning environment. Thus, consideration of methods to support effective group structuring and team assembly are critical to address, particularly in the initial phases of collaborative learning.

Scaffolding of the collaborative learning environment and use of varied digital tools that support collaborative learning are useful for orienting learners to new instructional approaches and settings (Quintana et al., 2004). For example, skills such as identifying key tasks, estimating the group workload, distributing tasks among group members, and accountability are new to many learners. Thus, scaffolding activities, such as modeling effective collaborative learning with gradual fading, are useful for setting expectations and outlining the structural makeup of groups (Collins, 1991). Additionally, effective scaffolding can support feedback mechanisms, group management, the role of leadership, and illustrate appropriate team member interactions—all processes necessary to turn a "group" into a "team." However, we have to be mindful that some students prefer to work individually. These "lone-wolves" may prefer learning on their own and in certain cases, depending on whether the task at hand benefits significantly from teamwork, this desire might be accommodated.

Effective group and team assembly approaches are pivotal to the success of collaborative learning environments. Although there is much existing research on this topic, it is limited in STEM contexts, and has not explored the use of advanced digital tools, data analytics, and other methods for supporting team assembly. A variety of areas for future exploration in this realm include: (a) optimizing team size with tasks and goals, (b) team assembly *via* advanced learning technologies (e.g., social networks, learning management systems), and (c) interest-based team selection (e.g. self-selection, social style).

Team Roles

Orienting students to team roles is an important task to increase learner engagement in the collaborative learning process (Herrenkohl, Palinscar, Salvatore, & Kawasaki, 1999). Understanding the various roles within a team, as well as the responsibilities and associated tasks aligned with each role, are important processes to establishing effective collaborative learning environments. Although identifying the various roles, responsibilities, and tasks is a necessary and critical step in team formation, it is also vital to distinguish between social, cognitive, and task functions (Dillenbourg, 1999). Prior to determining teams and team roles, a variety of approaches may be taken to ensure that students are well matched by role, such as a personality assessment or measuring transactivity (Feichtner & Davis, 1984). This may be useful, as it can be quite challenging to have a team comprised wholly of students who are relationship-oriented versus task oriented, or a team leader who provides inconsistent interactions with team members. The Myers–Briggs Type Indicator and other social styles assessments have also proven useful for students to find an awareness of self, how they interact with others, and how this plays out in the real-world. Another option might be the team-role questionnaire from Belbin (2012), which can be used to form teams based on a distribution of roles, or teams designed specifically to match diverse roles and other team characteristics, including their engagement. This can lead to an important class discussion on what team processes are and how they should interact with each other, including whether there might be an opportunity for shared leadership within the team. If students have input into the team formation, it is important to make sure they have criteria that are learning-focused, so that they are not making decisions based on friendship and cultural similarity. It may prove an interesting research question to explore how assembling teams based upon complementarity of social roles on a team can be used to maximize collaboration effectiveness and how one can avoid the natural social media echo-chamber effect on team formation.

In addition to breaking students out by social/cognitive/task roles, other options such as skeptic, scribe, leader, researcher, and communicator, have proven successful. Mathieu, Tannenbaum, Kukenberger, Donsbach, and Alliger (2015) identify key roles of organizer, doer, challenger, innovator, team builder, and connector. In addition, Belland, Glazewski, and Ertmer (2009) discuss improved learning outcomes, particularly for mainstreamed students (i.e., special needs students placed in general education classrooms) as a result of assigning team roles such as group manager, guidance provider, and task performer. The roles can also be established based on the type of activities that will be completed by the team. Furthermore, it can be useful to rotate roles so we challenge students to step outside their comfort zone and take on roles that may not be their natural inclination. This also helps students to see the team process from different vantage points. Moreover, frequently re-assigning or re-permuting students minimizes the risk that the group assignment and any outstanding conflicts negatively impacts group or team dynamics.

There will always be many roles not anticipated by the instructor. Ultimately, whether instructors choose self- or forced-team selection will depend on their goals for the activity. Are they looking for the best average team, equally-divided teams, or best-best team? Self-selection may produce the best-best team, but may leave others in poorer teams so that the average is lower (think back to team selection in elementary school gym class!). Learning versus productivity is a second level with this—is the product the primary goal, or is learning the primary goal?

Establishing Team Norms

Although the scope of, expected adherence to, and ability to self-establish norms is highly dependent on the learning environment and time constraints, establishing such norms is critical to the effectiveness of team dynamics, and is most effective when norms are derived and developed by team participants (Scardamalia & Bereiter, 1996). Subsequently, these norms can be used by learners at varied academic levels and can serve as useful reminders for learners to abide by the primary tenets of the norms, as well as serving as a deterrent for common team issues, such as social loafing. Team norms are especially crucial to help students engage in socially shared regulation of learning (Järvelä & Hadwin, 2013). By generating a shared understanding of how to collaborate, students can then manage expectations about goal-setting, planning their tasks and addressing challenges that they may face when working collaboratively.

A jigsaw pedagogy can also be a useful tool for facilitating the establishment of team norms, as each learner possesses elements of data essential for task completion, particularly as the jigsaw pedagogical approach scaffolds learners on the process of sharing ideas and then negotiating among team members. Although initially a time-consuming process, such team dynamics and role-scaffolding activities can serve as valuable lessons for learners, and can provide mechanisms for accountability within the collaborative environment (Saleh et al., 2018a; 2018b).

Task Relevance and Agency

Using grades as a motivating factor for activity completion is often insufficient. Consequently, grades in combination with other pedagogical approaches and structures are necessary to appropriately incentivize learning experiences. Such approaches and structures include (a) evoking interest and providing relevance to learners; (b) providing opportunities for shared goals, focusing on real-world problem issues and concerns; and (c) affording students with agency, perhaps via development of a measure of individual learner contributions in the collaborative learning process.

Communication

Communication is a key component of any team process, and processes should be outlined as part of the team norms, as social interaction preferences can inform how learners might manage their communication. For example, feedback is an essential form of communication in a collaborative learning environment, as it can serve as an option of encouraging students during the teamwork process (often in real-time via technological applications). Thus, in providing effective feedback in a team setting, it is important to consider a multi-layered approach; there should be both periodic team and individual evaluations, as well as evaluations based on both processes and products. These can often be mediated by digital tools, such as LMSs, which can provide a dashboard (familiar especially to those students who are gamers) that individually shows each student their level of contribution relative to the collective patterns of other members of the team (Bodemer & Dehler, 2011). Other options include a system like Classcraft, or a voice-activated device that allows advisory feedback.

Students tend to respond to feedback (particularly open-ended feedback) from peers, rather than an authority figure. Consequently, soliciting peer feedback throughout the collaborative learning process can improve the overall effectiveness of the learning environments, as well as help to moderate faculty workload, shifting focus from an assessment perspective to a more facilitative/instructional/mentoring perspective. As self-reflection is also a critical element of feedback, it is important to consider varied and frequent approaches to integrating such elements into the feedback and communication process of DMTL events.

Incentivization

Incentivization is an important consideration when developing any learning experience, and is particularly important in collaborative learning experiences, where an individual's performance will influence the experience of multiple learners. As previously mentioned, task relevance and providing for each learner's agency in the development of teamwork assessments are important to address. There are a variety of additional incentivization approaches and considerations, including: (a) utilizing a point and/or rating system to reward positive team collaboration that impacts products, processes, and outputs, and clearly differentiating between each; (b) affording learners opportunities to appropriately, effectively, and contextually rate the contributions of fellow team members (research should explore how assembling teams based upon complementary social roles on a team can be used to maximize collaboration effectiveness, which can then be used to help understand, for example, how students respond differently to peer feedback); (c) establishing project milestones and using time parameters to gamify the experience (e.g., through scaffolding or a leveling system); (d) establishing recognition parameters and opportunities for both whole team performance and individual excellence within teams; (e) capitalizing on co-orientation to the subject matter, future profession, *and* community built among students on task and group orientation; (f) supporting agency and accountability through modeling and clear/thorough role delineation; and (g) providing diverse feedback structures and opportunities to reconcile perceived differences in feedback, and others. Others include reward structures such as changing team roles (e.g., promoting students to "learner leaders"; Paulin & Haythornthwaite, 2016). Providing examination of incentivization techniques for DMTL is an area with limited existing research, so there are numerous opportunities for short- and long-term exploration.

Pedagogical Approaches

From the discussion associated with the sub-theme, "maximizing the student role in team management and minimizing the instructor role, via pedagogical approaches," several characteristics and key issues to consider emerged for consideration of further examination when designing, developing, and implementing pedagogical approaches to support DMTL:

- Facilitating team- and problem-based learning and other inquiry models by providing challenging and meaningful tasks to teams while using backwards planning and appropriate grouping strategies to ensure success and rubrics to evaluate progress, following guidance from Ertmer et al. (2009).
- Providing challenging and meaningful tasks to students through other research-based instruction strategies including service learning, inquiry-based learning, and project-based learning (Froyd, Borrego, Cutler, Henderson, & Prince, 2013).
- Differentiating collaborative learning processes from the products is important. As management of the team workflow is different from thinking about learning outcomes, learners need to be sensitive to the different outcomes for which they might be held accountable.
- Providing both formative and summative, as well as expert and peer, feedback is vital to the team process, but can also be an important pedagogical tool (Michaelsen & Schultheiss, 1989).
- Establishing shared cognition is critical, and can be used to create synergy. Interestingly, learners are unknowingly applying theory, while simultaneously learning theory, which

can lead to epiphanies in the classroom. This can also lead to a discussion of socially shared regulation and other regulations.

- There is power in activity theory, play, and learning (Danish, Enyedy, Saleh, Lee, & Andrade, 2015).
- Virtual environments can be challenging, but done correctly, can provide real-world learning experiences, which is a key tenet of meaningful learning experiences (Howland, Jonassen, & Marra, 2013; Jonassen, 1995).

Challenges

While these characteristics and issues provide researchers and practitioners with numerous opportunities for exploration, there are additional challenges related to DMTL to consider. Challenges identified included:

- In terms of gamification and learning, there is an issue of avoiding "seductive details" which are interesting but ultimately a distraction, and balancing fun and learning is always critical (Adams, Mayer, MacNamara, Koenig, & Wainess, 2012).
- Moderation of the team process in real time is critical to ensure that dialogue remains professional and that someone is paying attention for any coded or meaning-laden language, such as racial/ethnic/cultural/gender biases. This may be an opportunity for the supervision of the discussion by an agentic computer program, with predetermined decisions regarding how to proceed if the agent detects unprofessional or biased language.
- Students form cliques quickly and intrinsically, and as such, we must observe this behavior and make every effort to defuse it in the classroom or team setting.
- It is important to address the digital aspect; what is lost or gained when the team process is conducted within a technology environment? Are there tradeoffs between face-to-face and online learning environments? Do certain groups (perhaps K–12) need more face-to-face support than other groups?
- A set of metrics are needed indicating competencies and standards for excellence. This includes processes and specific outcomes for K–12 and/or higher education and can be arranged in hierarchies such as essential, desirable, and optional competencies (Earnest, 2005).
- Standards for effective assessment are needed.
- We must ask—what motivates students to fully participate in a digital ecosystem, and can we provide such motivation?
- Do team challenges vary as a function of pedagogical tasks or contexts?
- Classification of DMTL and how it relates to goals, pedagogies, methods, assessments, and research should be differentiated for synchronous versus asynchronous environments; on-campus, hybrid, and distance learning environments; and scope of group/teamwork based on size of project, time for completion, and group size.

As outlined here, it can be challenging to rethink the systems that we are in but it is even more critical to challenge the "center" of the field in order to promote change (i.e., what counts as participation in DMTL, what are the goals of DMTL, how does DMTL relate to the needs of the field in 5 years). Borrego and Henderson (2014) have outlined specific strategies which can be taken to bring about such a change, but the key remains novel and improved ideas. For this reason, we have established 1–3–5 year goals and research objectives, outlined in Table 11.

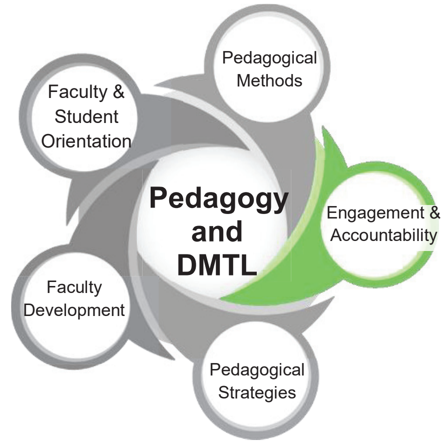
Table 11

Research Opportunities to Examine Pedagogical Methods for Team Management

Dimension	1-Year Research	3-Year Research	5+ Year Research
Maximizing student role(s) in team management	• Conduct multidisciplinary reviews of state-of-the-art in DMTL. • Conduct focus groups with learners (K–20) to determine their experiences in DMTL (e.g., team management and collaboration).	• Analysis of themes from focus groups → share themes with a smaller group that is representative of the learner population to discuss next steps and design an action plan. • Examination of approaches to prepare STEM faculty/teachers to support student-centered DMTL.	• Unpacking interdisciplinary approaches that focus on team management. Research should focus on integrating these perspectives, or understand the extent to which these perspectives align (or not). What are the challenges in integrating these perspectives?

Supporting team management via pedagogical strategies	• Develop best practices and implementation strategies for mixed realities and other DMTL technologies.	• Evaluate the impact of reforming teams frequently versus the use of consistent teams (e.g., shared mental models, learning outcomes, soft-skills outcomes).	• Examining best practices in workplace DMTL and applications/alignment in K–20. • What are best practices in inquiry approaches to supporting team management in the context of digital environments for K–12? There is a wide range of what we mean by inquiry—what is the relationship between managing the team and inquiry processes?
Group selection processes and team management	• Observation/ ethnography of affective and social experiences of DMTL in higher education [F2F, hybrid, and fully online]. • Review and assess the characteristics of the most successful mainstream gaming platforms that support DMTL.	• Exploring the role of social capital in DMTL teams.	• Longitudinal examination of the effectiveness of design characteristics of new DMTL environments, pedagogical approaches, and new constructs related to team selection and management.

Theme 3B: Engagement and Accountability



Theme Editors: Eloy Hernandez, Richard Hartshorne, and Asmalina Saleh

Introduction

Before we start talking about engagement and accountability in DMTL, we need to provide broad definitions for both concepts and make a distinct separation between engagement and motivation. This last remark is crucial because a typical misconception in the community is that in order to increase learner engagement, motivation is essential. This is not necessarily true for one can be motivated and not engaged and vice-versa. Although engagement is usually the "what," motivation is typically the "why" (Galloway, 2016). Put another way, engagement is what links motivation and learning (Sinha et al., 2015). Of course, they can both work synergistically in education because one can affect motivation both intrinsically and extrinsically, thus positively influencing engagement.

Student engagement in learning depends on three main factors that keep the individuals involved in any activity in the classroom or online—their emotions, behaviors, and thought processes (Fredricks, 2014). In order to promote students' engagement in an educational environment, one needs to find ways to affect any of these three factors to help students realize that they are learning and that through the learning experience, they are achieving something of value. According to James (2014), instructors who want to effectively engage students in learning activities need to be mindful about how to apply the following six elements: "make it meaningful," "foster a sense of competence," "provide autonomy support," "embrace collaborative learning," "establish positive teacher–student relationships," and "promote mastery orientations" (paras. 3–8).

When we think about motivation in student learning, one needs to think of what drives the behavior of these individuals in the classroom or online to attain satisfaction and avoid dissatisfaction. This perspective derives from Herzberg's two-factor motivation theory, broadly used in management but scarcely employed in education. For determining how to motivate student learning, one needs to figure out what are the real needs of students in their corresponding environments. It is known that for the most part, needs tend to evolve from external to internal motivation. Therefore, promoting collaborative learning, treasuring teamwork, and promoting a sense of contribution and accomplishments using external nudges can promote a culture of learning with a purpose.

In order to increase motivation and engagement, simultaneously, one needs to make sure that the learning ecosystem eliminates demotivators while one retains motivators and rewards students for their achievements and contributions. One should not ignore that new flexible learning spaces and adaptable IT capabilities engage and motivate students in learning. Having established the differences and similarities between engagement and motivation, we can proceed to define student learning accountability. This construct refers to keep students committed and connected to their learning. When we talk about student learning accountability, we seek to help students take ownership and responsibility for their own learning. A strategy we endorse herein to enhance accountability among students centers on the creation of independent collaborative educational ecosystems and providing clear guidance for expectations and assessments.

Motivating Learners in DMTL

A key consideration in increasing learner engagement, particularly in DMTL, is motivation, which is complex and often a research topic. While much research has been conducted on motivation and collaborative learning, the knowledge base related to motivation and DMTL is sparse, particularly in STEM contexts. Consequently, it is important to holistically consider factors and characteristics of pedagogical and assessment approaches in DMTL that maximize learner motivation, and ultimately positively influence engagement in the learning environment. Such issues and structures to consider include: (a) individualizing incentivization; (b) structuring learning scenarios; (c) utilization of role roadmaps and checkpoints as tools for assessing engagement and participation; (d) providing links to future workplace practices (randomized team selection, DMTL approaches in varied workplace settings); (e) examining the role of simulated consequences for positive actions as well as failure to act or poor decision-making; (f) exploring the role of diversity and inclusion (addressing shunning, ignoring, or actively working against others in the group); (g) identifying the role of team norms to help overcome conflict and facilitate a motivating and inclusive DMTL setting; (h) establishing comprehensive “best practices” for group monitoring and encouragement of effective team practices; (i) exploring task/activity/goal types that facilitate motivation and engagement (i.e., mastery orientation vs. performance orientation coordination vs. collaboration); (j) integrating higher order goals, such as in the motion picture *Apollo 13* where a team had to create a carbon monoxide filter to save the astronauts, and the influence of seeing one’s goals as part of a larger goal, as a mechanism for engagement in DMTL; (k) exploring the role of the scale of time or difficulty and frequency of team composition modifications and the influence on engagement; (l) diversification of individual and group grading components of DMTL and their influence on engagement; and (m) exploring the influences of game-based and problem-based learning approaches, where students are motivated by the designed contexts, on learner engagement. Considering these approaches and their impact on motivation and engagement will improve the diversity, inclusivity, and effectiveness of DMTL settings.

Accountability for All in DMTL Environments

Even the most seasoned instructor who integrates collaborative learning as a key pedagogical approach often struggles with ensuring and measuring accountability of individual team members, as well as the group as a whole. There are a number of strategies and associated issues to consider in ensuring individual accountability, the performance of the group as a whole, and a positive environment. These include: (a) understanding varied characteristics or participation and learning, (b) making participation visible (e.g., network diagrams of participation, perhaps from digital records), (c) increasing the role of accountability in the DMTL process by allowing students to take the lead, (d) assessing team contributions and providing feedback (both peer and instructor) based on individual contributions, and (e) considering how to account for passive learning (with a high level of cognition/learning). Of course, one should not ignore that to truly promote learning accountability among students, instructors need to set clear expectations from the very beginning, and state specific learning objectives for each session.

Grouping Strategies to Increase Engagement and Accountability

Although engagement and accountability are most definitely different constructs in DMTL, and there are numerous team development strategies in this field, it is important to consider the potential for merging best practices related to team formation, increasing engagement, and providing effective accountability measures and processes for both individuals and the team as a whole. Whether by pre-reading activities, readiness assessment tests, or in-class activities, providing a collection of both similarities and differences related to the best practices associated with these unique aspects of DMTL has the potential to enhance the effectiveness of DMTL settings in STEM. This approach would in turn, help optimize the orientation of learners to these relatively new learning environments, as to deepen the professional development of faculty and instructors to implement emerging DMTL-based pedagogical practices.

Pedagogical Approaches to Enhance the Development of Soft-Skills

Extensive diverse collaborative learning models that afford learners numerous opportunities to develop soft skills (National Academies of Sciences, Engineering, and Medicine, 2017), which are becoming increasingly important in STEM careers, exist in a variety of fields, but are not typically integrated into STEM instructional settings. Flipped classroom methodologies (Mazur & Hilborn, 1997), team-based learning, and "Johnson's Learning Together Techniques" (O'Donnell & Kelly, 1994) are a few such pedagogical methodologies that have gained traction in varied STEM settings. Other inquiry-based pedagogical approaches and models support the development of leadership and other soft skills, with Socially Shared Regulation of Learning (SSRL), self-directed learning (SDL), and co-regulated learning as possible models to support these pedagogical approaches. Extending these, it is important to consider the role of technological applications to support the development of soft skills, as well as how the integration of digitally-mediated environments (i.e., technological applications) impacts both what soft skills are important, as well as the emergence of new soft skills.

Challenges

Although these characteristics and issues provide researchers and practitioners with numerous opportunities for exploration, there are additional challenges related to engagement and accountability in DMTL, including but not limited to:

- How can one use DMTL to maximize individualization of incentives when structuring new learning scenarios?
- What is the role of simulated consequences for positive actions and poor decision-making in a DMTL space?
- How can one address exploring the role of diversity and inclusion in a virtual environment, and what are the characteristics of team standards to address conflict resolution and facilitate group identity in a digital setting?
- Develop strategies to proactively promote randomization in team selection in DMTL.
- Explore the influences of game-based and problem-based learning approaches in a virtual space.
- Investigate and understand new approaches that facilitate motivation and engagement in DMTL, and study the role of the scale of time, difficulty, and frequency of team composition modifications and the influence on engagement.
- Increase the role of accountability in the DMTL process and understand the multiple characteristics of participation and learning, and make participation visible in a digital environment.
- Assess team and individual contributions and account for passive learning in DMTL.

For these reasons, we have established 1–3–5 year goals and research objectives outlined in Table 12.

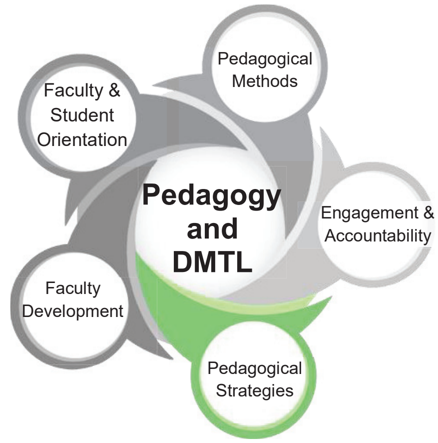
Table 12

Research Opportunities to Examine Engagement and Accountability in DMTL

Dimension	1-Year Research	3-Year Research	5+ Year Research
Maximizing student accountability	• Explore the effectiveness of short-term professional development opportunities for faculty to learn to use analytics to manage and evaluate team processes. • Measure the effectiveness of varied approaches/models of peer evaluation and/or peer feedback. • Focus group to determine student needs for understanding/using DMTL analytics; how to make analytics accessible to students / instructors. • Survey of instructor use of analytics as a tool for accountability.	• Assessing and engaging individual and group learning outcomes. • Exploring varied point/credit allotment models and the influence on engagement and team accountability. • Integrate the use of dashboards as a means to promoting visibility of teamwork and determine useful metrics, supporting faculty and student support for DMTL. • Explore models of cultivating a culture of accountability within student life as opposed to a culture of policing? • Measuring validity and reliability of assessment instruments (both individual and group).	• Identify best practices for building team accountability? Develop and measure the effectiveness of accountability tools. • Develop a guidebook/resource for instructors? •

Increasing student engagement	• Develop best practices and implementation strategies for mixed realities and other DMTL technologies.	• Examine models of motivating/orienting faculty/students to support engagement and accountability in DMTL?	• How can we facilitate collaborative interactions with advanced learning technologies?

Theme 3C: Emerging Pedagogical Strategies



Theme Editors: Chris Dede, Richard Hartshorne, Leanne Coyne,
and Jody K. Takemoto

Introduction

The most transformative uses of collaboration technologies in
education create or support sustained communities of learners,
educators' communities of practice, and knowledge building experiences (Dillenbourg, Baker, Blaye, & O'Malley, 1995; Laurillard, 2009; Fishman & Dede, 2016). Emerging technologies such as XR (including virtual, mixed, and augmented reality) and AI can aid with core aspects of knowledge advancement, such as iterative "idea improvement" and the creation of "epistemic artifacts" that externalize knowledge as the goal of the learning enterprise (Scardamalia & Bereiter, 2006). Social media, while no longer novel, are continuously evolving new affordances based on a tacit epistemology that "knowledge" is collective agreement about a description combining facts with other dimensions of human experience, such as opinions, values, and spiritual beliefs. Within this framework, expertise is an attribute of the community as well as its individual members and involves understanding disputes in detail and proposing syntheses that are widely accepted by the group (Dede, 2016).

These emerging/evolving tools and media pose challenges for teaching because they involve a different epistemology than communicating and assimilating pure factual information. Immersive authentic simulations based on XR enable types of collaborative learning that prepare students for life as well as for further academic work, and the various types of real-time information they generate provide opportunities for diagnostic assessment embedded in learning and formative assessments for process improvements by teachers and students (Dede, Jacobson, & Richards, 2017). AI offers a type of cognition and knowledge generation complementary to human beings in its strengths and limitations (Center for Curriculum Redesign, 2019). Research is urgently needed on how to use these powerful technologies well and transformatively via innovative instructional methods, rather than simply automating conventional approaches to collaborative learning that are no longer sufficient in the era of the Fourth Industrial Revolution (World Economic Forum, 2019).

Innovative Pedagogical Approaches and Student Achievement using DMTL.

By their nature, innovative and emerging pedagogical approaches have extensive issues for consideration. This is due in part to the complexities associated with the STEM content area and instructors typically lacking expertise in the implementation of innovative, emerging pedagogical approaches, further complicated by the integration of digital mediation. That said, there are extensive opportunities for groundbreaking research examining best practices of innovative pedagogical approaches and student achievement using new tools, media, and experiences for fostering DMTL. Such opportunities and issues to consider include: (a) integrating XR into DMTL environments, and examining what it means to support XR-based learning environments; (b) studying factors that maximize the quality of XR learning; (c) merging embodiment and play with XR-based pedagogical approaches; (d) visualizing student-centered XR pedagogical approaches; (e) considering how embodied cognition support collaboration and team-based experiences; (f) exploring the role of simulations of collaborative and team-based experiences in STEM learning environments; (g) examining simulations for development of soft skills, as opposed to solely knowledge-based outcomes, in DMTL settings; (h) exploring interactions with non-human teachers/facilitators and team members (i.e., robots, AI); (i) examining the role of AI in team processes and formation; (j) identifying limitations/drawbacks of XR, AI, and other emerging technologies in STEM DMTL settings; (k) exploring the role of technology in assisting team learning; (l) examining the impact of using AI and other technological applications to reallocate instructor workloads; and (m) investigating the impacts of the novelty effect (return on investment, etc.) on the integration of advanced and innovative learning technologies and associated pedagogies on learner achievement, soft skills, and other instructional outcomes.

Aligning Pedagogical Practices with the Integration of Virtual Reality, Augmented Reality, and Other Emerging Digital Tools in STEM Education

As outlined in the 2019 Horizon Report (Alexander et al., 2019), XR technologies are particularly appropriate for student-centered and active learning. Whether simulation, virtual reality, augmented reality, mixed reality, or 360° video, learners are able to experience scenarios, as well as very quickly manipulate scenario variables, in ways that were not possible in the not-so-distant past, significantly affording learners with an ever increasing range of tasks, experiences, and activities. In addition, AR allows students to explore complex content through physical movement as one possible implementation of Vygotsky's notion of play (DeLiema et al., 2016). However, with great power comes great responsibility, and the emergence of these tools has highlighted an increased need of STEM instructors to become proficient at identifying, developing, and integrating appropriate pedagogical strategies to support the inclusion of these emerging technologies into the instructional setting. For example, while XR facilitates active learning, reflection and self-assessment are not typically key aspects of these emerging technologies. So, how do instructors maximize both the pedagogical benefits of DMTL and these emerging technologies, while simultaneously minimizing the drawbacks of each? Further complicating the effective integration of these emerging technological applications into STEM instructional settings, is the alignment of pedagogical practices that also support specific instructional outcomes alongside the previously mentioned issues. Therefore, considering the most appropriate DMTL-based pedagogical approaches that integrate emerging technologies will look very different depending on the focus of the instructional outcomes (e.g., digital literacy, reflection/metacognition, problem-solving, embodied cognition, problem-based learning, ideation, etc.). For the integration of XR to be effective, it is critical that STEM instructors become versed in the alignment of learning outcomes, pedagogical approaches, and the functionality of emerging technological applications.

Future Possibilities of Innovative and Emerging DMTL-centric Pedagogical Approaches

The ability of emerging and future technologies, such as XR and AI, to afford learners with personalized learning experiences, reallocate faculty and learner workloads, and support the analysis of complex data to support DMTL, provides significant promise for future STEM learning environments. With the emerging growth and adoption of such tools necessitate revisiting pedagogical strategies that support collaboration, learner engagement, and the development of problem-solving and critical thinking skills, while also facilitating curiosity and engagement among learners. All of these factors are foundational for student success, and serve as critical considerations for future research and development in STEM education (Alexander et al., 2019). Additional opportunities and issues to consider include: (a) the consolidation of machine learning in DMTL environments (i.e., best practices about collaborative learning and machine learning), (b) the use of AI to support collaboration and to challenge expertise that would otherwise not be challenged (and vice versa), (c) the use of XR to increase social presence in DMTL, (d) voice activation and translation in real-time, (e) visual-based interactions that facilitate sharing and organization of knowledge, (f) joint attention tools that shape interactions, (g) eye tracking tools to support understanding of student learning, (h) technology as scaffolding tools, and (i) teacher support for classroom orchestration.

Challenges

While these characteristics and issues provide researchers and practitioners with numerous opportunities for exploration, there are additional challenges related to DMTL to consider. Challenges identified included:

- How can XR, play, and games/gamification support metacognition?
- How can administrator/faculty/instructor resistance (and incentivization) be most effectively addressed?
- How can student resistance be most effectively addressed?
- What strategies can be integrated to alleviate student apprehension (i.e., privacy in use of data)?
- In this complex landscape, what strategies are best for determining which emerging technologies align with particular pedagogical approaches and learning outcomes?
- What strategies most effectively address the technical challenges associated with the integration of these emerging technologies and the associated pedagogical approaches in STEM instructional settings (e.g., Wi-Fi quality, usability, cost, motion sickness, bulky equipment, etc.).

- What strategies are most effective for supporting individual learning as they cycle through multiple teams (e.g., personal learning spaces)?

As outlined here, addressing the integration of emerging technological applications in STEM settings in an increasingly complex landscape, while aligning their use with pedagogical applications and instructional outcomes, can be challenging, but a necessary activity to promote substantial and needed change. For this reason, we have established 1–3–5 year goals and research objectives, outlined in Table 13.

Table 13

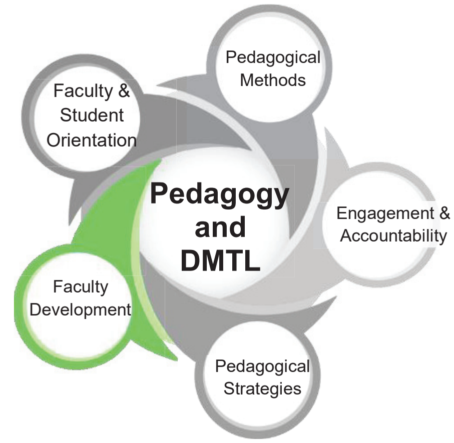
Research Opportunities to Examine Emerging Pedagogical Strategies in DMTL

Dimension	1-Year Research	3-Year Research	5+ Year Research
Extended realities	• Identify areas of highest need for XR (extended reality: virtual, mixed and augmented reality), development and instructor training • Establish XR preferences for students and teachers.	• Build and test prototype XR (VR, AR and MR) for STEM content. Identify unexpected issues and challenges. Fully explore instructor training needs. Assess perceptions of learning, engagement, and actual learning • Examination of approaches to prepare STEM faculty/teachers to support student-centered DMTL utilizing advanced learning technologies.	• Using eye tracking to determine team engagement in face-to-face, online, and XR team learning • Test entire XR courses and impact on learning • Can XR overcome the limitations of current online learning strategies? Should VR headsets replace computers for online courses? Will this enable us to have face-to-face classes and online classes that are almost identical?

Supporting integration of emerging pedagogical applications	• Focus groups, observations, surveys exploring the barriers for implementing emerging technologies and pedagogies?	• Identify best practices for instructor training on emerging technologies. • Examine the balance between inquiry designs that support agency and learning. • Gather the multiple individual experiences with using tech and DMTL in their own environments (meta-analysis; interview studies; workshops). • Articulate learning outcomes for use of DMTL, i.e., why should we do it. • Develop methods for analysis of DMTL. • Development/Synthesis of theories for DMTL. • How can we integrate narrative inquiry and performance theory (embodied learning and the importance of stories/storytelling) into DMTL? • Understanding team knowledge construction in DMTL, individual knowledge construction in DMTL, and the relationship between them. • Promoting, making visible, and evaluating social network analytic perspectives on actors, relations, emergent roles, and structures relevant to DMTL.	• What does it mean to scale these pedagogical approaches in the context of DMTL? • What are new pedagogies that will push the boundaries of how to support DMTL? • New theories for DMTL (pedagogy, andragogy, heutagogy) • How can we best integrate embodied learning approaches (e.g., embodied metaphors, grounded cognition, etc.) toward supporting collaborative learning in the context of technologies like AR/VR/MR? • What does it mean to implement emerging pedagogical approaches in the context of K–20 classrooms? • What does it mean to support teachers in supporting embodied learning? • What forms of data are needed to support learners and instructors as they engage in collaborative learning?

Synergizing pedagogy and technology	• Prioritize most opportune techniques and technologies to focus on; identify trade offs, including accessibility and ease of adoption.	• What is the effectiveness of library-based makerspaces for technology exploration and support for DMTL? • Compare the benefits of integrated technologies and systems (e.g., VR + AI + voice recognition) versus separate systems (e.g., one type of LMS, a different peer evaluation tool, etc.).	• Disseminate turnkey methods to adopt and use these techniques and technologies. • Establish a repository of digital team activities using cutting-edge technology and pedagogical approaches. • Develop personalized degree programs such as picking your own courses to build a customized degree program—in what ways can emerging technology be leveraged to do this? • How can we use emerging technology to gamify education? • What are some play-based pedagogies that can be used to support DMTL? What are the strengths and limitations?

Theme 3D: Faculty Development and DMTL



Theme Editors: Julie Donnelly and Richard Hartshorne

Introduction

Although identifying best practices for planning, implementing, and facilitating DMTL is a first step, considering how to encourage faculty to adopt these practices is the next necessary step. STEM faculty are content-area experts, but not necessarily pedagogical experts (Raker & Holme, 2014). Their knowledge of teaching relies primarily on experience rather than scientific evidence (Cooper & Stowe, 2018). In fact, even when they are aware of evidence that supports a particular pedagogical reform, a negative experience with using it is likely to deter them from using the reform repeatedly (Gallos, van den Berg, & Treagust, 2005). Further, recent research reveals that even when provided with tools that support active learning (e.g., flexible learning spaces), most faculty will continue to use didactic teaching methods (Stains et al., 2018). Thus, engaging faculty in effective opportunities for development related to teaching is an essential component of the propagation of DMTL. In addition to making faculty aware of pedagogical strategies related to DMTL, effective professional development programs will address the development of pedagogical reasoning.

Assisting Faculty in Developing Effective and Appropriate Pedagogical Strategies Related to DMTL.

Effective methods for assisting faculty in developing effective and appropriate pedagogical strategies are pivotal to the success of the widespread dissemination and adoption of DMTL environments in STEM education. Although there is extensive research on strategies, models, and activities that support faculty development, such research related to DMTL in STEM education is limited, and has yet to extensively explore the use of advanced digital tools, data analytics, team assembly, faculty teacher identity, and other issues associated with extensive pedagogical reform. A variety of areas for current and future exploration in this realm include: (a) optimizing the use of university centers for teaching and learning; (b) developing models and resources that align the emerging technological applications, pedagogical strategies, and STEM education; (c) providing symposiums highlighting effective tools to assist in solving pedagogical problems faculty may encounter; (d) supporting faculty with additional credentials, awards, and other incentives; (e) exploring characteristics of effective models of graduate student instructional preparation; (f) investigating the effectiveness of innovation frameworks, the adoption of multiple innovations, and the factors that influence readiness of faculty to integrate DMTL; and (g) exploring factors that influence or impede the adoption of effective DMTL pedagogical strategies.

Supporting the Development of Pedagogical Reasoning in Faculty

Pedagogical reasoning, or the values and ideas regarding teaching and learning, is a driving factor in an instructor's pedagogical decision-making process. Thus, devising effective strategies and processes for developing robust pedagogical reasoning that supports the integration of DMTL-related instructional practices is a critical component to increasing DMTL practices in STEM education. Although there is much existing research on this topic, it is limited in STEM contexts, and has not explored the use of advanced digital tools, data analytics, and other methods for supporting team assembly. A variety of areas for future exploration in this realm include: (a) optimizing team size with tasks and goals, (b) team assembly via advanced learning technologies (e.g., social networks, LMSs), (c) and interest-based team selection (e.g., self-selection, social style). A variety of areas for current and future exploration related to the development of pedagogical reasoning that supports the integration of DMTL in STEM education include: (a) distributing models that support faculty development related to high impact DMTL teaching and learning practices in STEM education, (b) exploring models that support the effective use of learner metrics and analytics from classrooms for instructors, (c) identifying methods of encouraging faculty to explore the use of emerging technological applications and pedagogical structures in STEM education, (d) the composition of communities where instructors share high-impact teaching practices, and (e) examining accreditation standards as drivers of reflective pedagogy (i.e., creating sound program and learning outcomes and closing learning and performance gaps).

Challenges

Although these characteristics and issues provide researchers and practitioners with numerous opportunities for exploration, there are additional challenges related to DMTL to consider. Challenges identified included:

- What strategies are most effective in developing a teacher identity and willingness to try new technological applications and pedagogical approaches among STEM faculty (incentives, reallocation of time, Scholarship of Teaching and Learning [SoTL], inclusion in tenure and promotion)?
- How do we encourage pedagogical risk-taking, innovation, and high impact teaching practices?
- What models and strategies are most effective for supporting faculty development in STEM education (workshops, development courses, peer networks, communities of practice, etc.)?
- What is the role of teaching and learning centers in STEM pedagogical reforms and faculty development?
- How are faculty development resources and tools disseminated in a manner that supports extensive use?
- How does faculty development keep up with continuously evolving technological applications and associated pedagogical processes?
- What are the best practices associated with developing and supporting undergraduates, graduate students, and post-docs?
- What is the role of innovation frameworks in faculty development?

As outlined here, addressing the faculty development and DMTL in STEM settings affords numerous opportunities and challenges, but is also an increasingly complex landscape.

For these reasons, we have established 1–3–5 year goals and research objectives, outlined in Table 14.

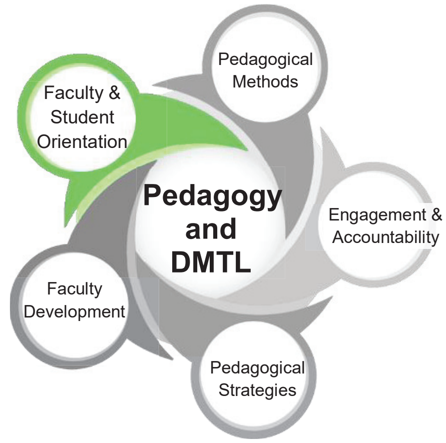
Table 14

Research Opportunities to Examine Faculty Development in DMTL

Dimension	1-Year Research	3-Year Research	5+ Year Research
Faculty/Professional Development	• Focus group and listening tour to identify best practices/processes, affordances, and constraints leading to a design symposium that enables experiences with new technologies but also works on developing the infrastructure needed to support future work. This could work at the instructor level—why do you use the technologies you use? At the institutional level—how do you select technologies to adopt, and how do you share them and support them with faculty? This could also work with developers of successful technologies—how did you develop your product, how did you promote its adoption, how did you sustain it? What about a student user level? Bring results of these listening tours	• Symposium (new technology, infrastructure, and practices to support new technology, developing standards for best practice and metrics) → design communities of practice that will live past the symposium. • Enhancing collaborations between instructional designer, instructor, and other stakeholders (administrators, students, etc.).	• Building communities of practices across campuses (new technologies, problems of practice). • Virtual innovation center that houses high-impact practices and a repository of resources. • Program for undergraduate and/or graduate students to become campus technology innovators / support specialists. • What are the roles and responsibilities of a faculty member with respect to DMTL?

	together—share student/faculty/ institution feedback with developers, and vice versa. • What are possible conceptions of core faculty skills with respect to DMTL?		

Theme 3E: Faculty and Student Orientation



Theme Editors: Richard Hartshorne, Julie Donnelly, Caroline Haythornthwaite, and Matthew Ohland

Introduction

As with any innovation, DMTL can be expected to diffuse in
accordance with the diffusion of innovations theory (Rogers, 2010).
Here we address the needed effort to reduce barriers to adoption so that DMTL is more likely to be adopted and used effectively by both students and faculty. First, although DMTL introduces benefits to students and faculty in terms of conceptual understanding in STEM, it also offers opportunities for students to learn how to work collaboratively in a way that is effective. Exercising these skills will ensure that students become DMTL learners, proficient in collaborative learning. However, students do not possess skills for effective collaboration by nature. Explicit instruction and deliberate practice working on teams is necessary for successful DMTL participation and development of a skill valued by most 21st-century employers (Michaelsen, Knight, & Fink, 2002). Faculty are the other most important agent in the propagation of DMTL. A survey of engineering department chairs revealed that word of mouth and conference presentations were more effective methods of communicating pedagogical reforms than publications (Borrego, Froyd, & Hall, 2010). Thus, effective development of early adopters and encouragement to disseminate results to their peers in less formal settings will help influence the early and late majority of faculty adopting DMTL. The pedagogical reasoning, knowledge of DMTL pedagogies, and experience using DMTL held by early adopters will be an invaluable resource to faculty interested in adopting DMTL.

Preparing Learners as Mentors and Scaffolding Learners to Enhance the Effectiveness of DMTL

As students play a critical role in the teaching and learning process, effective methods for scaffolding learners in DMTL processes and procedures are pivotal to the success of the widespread dissemination and adoption of DMTL environments in STEM education. Although there is extensive research on strategies, models, and activities that support faculty development, such research related to orienting students to DMTL environments in STEM education is limited. A variety of areas for current and future exploration in this realm include: a scaffolding learners on DMTL-related approaches at younger ages (with gradual disengagement/fading), b) developing models and resources for teaching communication and other soft skills, c) exploring methods of facilitating learner agency in the DMTL environment, d) examining methods for monitoring and measuring individual learner contributions and self-reflection of those contributions, e) highlighting reflection and metacognition as soft skills in the DMTL process, f) examining the role of competition within a group/team learning setting, g) experimenting with learner achievement/experience level pairing and team composition, and h) developing a program-wide space/community for sharing DMTL experiences where more experienced DMTL learners pass on knowledge to newer DMTL learners.

Models of Faculty Development that are Most Effective for Supporting DMTL Instructional Skills

Effective models of fully developing DMTL pedagogical skills of K–20 faculty are pivotal to the success of the widespread dissemination and adoption of DMTL environments in STEM education. As previously mentioned, while there is extensive research on strategies, models, and activities that support faculty development, such research related to DMTL in STEM education is limited, and has yet to extensively explore the alignment of these strategies, models, and activities that support faculty development with those that orient learners to effectively participate in DMTL environments.

A variety of areas for current and future exploration in this realm include: (a) optimizing collaboration between instructors, learners, and instructional support mechanisms, (b) developing models of joint faculty–learner recognition (i.e., credentials, awards, etc.), 3) exploring effective alignment of incentives for faculty and learners, and (d) supporting DMTL partnerships among institutions (both faculty and students).

Challenges

Although these characteristics and issues provide researchers and practitioners with numerous opportunities for exploration, there are additional challenges related to DMTL to consider. Challenges identified included:

- What is the role of gamification, learning, and balancing fun/learning (Adams, Mayer, MacNamara, Koenig, & Wainess, 2012)? How is this effectively addressed with orienting faculty and students to DMTL technological applications and pedagogical strategies?
- How do we effectively moderate team processes in real-time to ensure that dialogue remains professional and appropriate?
- What technological applications and/or pedagogical strategies minimize the formation of student cliques in DMTL?
- What are the most effective strategies for facilitating DMTL in different disciplines and domains?
- How do we explore what is lost or gained when the team process is conducted within a technological environment? Are there tradeoffs between face-to-face and online learning environments? Do certain groups (perhaps K–12) need more face-to-face support than other groups?
- What metrics indicate competencies and standards for excellence in DMTL settings (processes and specific outcomes that are specific to K–12 and/or higher education)?
- What are standards for effective assessment?
- Beyond orientation, what strategies are most effective in encouraging students to fully and effectively participate in DMTL?
- How do team challenges vary as a function of pedagogical tasks or contexts?

- How do we encourage all STEM disciplinary communities to value innovations in teaching and learning, as opposed to research productivity?

As outlined here, there are numerous opportunities and challenges associated with orienting both faculty and students to effectively and appropriately participate in DMTL. For this reason, we have established 1–3–5 year goals and research objectives, outlined in Table 15.

Table 15

Research Opportunities to Examine Faculty and Student Orientation to DMTL

Dimension	1-Year Research	3-Year Research	5+ Year Research
Faculty / Professional development	• Faculty moving into online and blended learning spaces are already doing a lot to manage integrating new approaches and technologies—identify groups / gatherings of people learning to teach in those modes and identify barriers to using teams in those classes. • How to extend faculty support for DMTL in their programs/departments? • Review of current literature regarding faculty development and orientation to digitally mediated classroom technology (e.g., Special and Digital Collections at the	• When it comes to increasing SoTL support for STEM education, incentivizing collaborations between learning sciences experts and subject-matter expertise would be helpful.	• Combine fundamental science questions (the disciplinary-based research need) with the educational goals (the learning sciences need)? For example, can NSF's Research Experiences for Undergraduates program be adapted so that it is not simply supporting the disciplinary based science, but also contributing to the STEM education needs more generally? As a use-case, this could involve a basic science Marine Biologist who studies something like fisheries depletion in small coastal towns, collaborating with a Biology Education faculty member.

	University of South Florida). • Survey faculty regarding what they need to support their use of DMTL.		
Student orientation	• Augment the pipeline: doctoral students, post-docs, junior faculty.	• Not Applicable.	• Not Applicable.
Synergizing faculty and student orientation	• Focus groups to define DMTL best practices.	•	• Explore what works or does not work related to DMTL, both in use by teachers and with the approach itself in order to orienting faculty and students. • What are effective, scalable, feasible approaches to the faculty and student orientation?

Chapter 6

Track 4: Empowering Equitable Participation through DMTL

Introduction

Inclusivity in educational environments has been a known concern (Annamma & Morrison, 2018; Nachman & Brown, 2019) whether in MOOCs (Rolfe, 2015), traditional STEM disciplines in higher education (Moriña, 2017; Tennial et al., 2019), or in online education (Dowell, Lin, Godfrey, & Brooks, 2019; Millheim, 2015). Due to this concern, inclusivity in digital-mediated learning environments were explored during the workshop as it related to building learning teams in STEM. Areas of inclusivity discussed included: (a) ethnicity, (b) gender, (c) neurodiversity, (d) accessibility, (e) culture, (f) intercultural collaborations with global diversity, (g) geographical inequalities, and (h) intergenerational differences.

The intersectionality of multiple minoritized identities ([dis]ability, neurodiversity, race/ethnicity, gender, sexuality, socioeconomic status, religion, mobility, culture, and generations) in digital environments are factors that need to be understood through research and practice. Throughout each area of inclusivity there was a commonality expressed that technologies, such as simulation and virtual reality, could be leveraged to prepare educators for individual and intersectional diversities among students. Immediate solutions, such as training to uncover personal unconscious biases and connecting the potential impact of these biases on pedagogical practices, begins with educators uncovering their own identities (Killpack & Melón, 2017).

During this workshop, inclusivity (theory, practice, and research) were discussed in relationship to STEM and digitally-mediated team learning in higher education. These topics included:

Theme 4A: Engaging Communities of Diversity
Theme 4B: Fostering Inclusivity through DMTL
Theme 4C: Equity and Diversity
Theme 4D: Transferability and Sustainability
Theme 4E: Possibilities of DMTL

The following chapter explores the state of the field, challenges and benefits of implementation, context, and potential research related to DMTL in STEM for the next five years and beyond.

Theme 4A: Engaging Communities of Diversity

- What are the general communities of diversity in learning?
- What are potential perceived barriers towards learner engagement in DMTL?
- Are there examples of potential affordances towards learner engagement in DMTL?

Inclusivity encompasses the human aspects of learning in a community of learners. The social characteristics and associations of a person may attribute to how a person identifies and acts in social circumstances. Identity has been linked to a person's self-efficacy, confidence, and motivation to interact and contribute. For instance, teachers that have a low self-efficacy in teaching science tend to not teach it at the same level of confidence that they teach higher self-efficacy subjects. Likewise, in the same way learners' identity (consisting of multiple factors including community identity) can impact their self-efficacy and willingness to interact in learning contexts like STEM.

Ethnicity

The underrepresentation of varying ethnicities in STEM is known. The inequalities of ethnic representation have contributed to underrepresentation in the STEM workforce (Riegle-Crumb, King, & Irizarry, 2019). In forming teams for problem-based learning, student team members realized and valued the importance of sociocultural diversity (Bani-Hani, Al Shalabi, Alkhatib, Eilaghi, & Sedaghat, 2018). Fostering success of ethnically diverse students in STEM is considered to be essential. Increasing equitable social and ethnic diversity in participation rates in STEM education leads to a more multiethnic workforce in STEM. Increasing ethnic diversity in STEM fields promotes greater global collaboration and innovation. Recruiting, preparing, and maintaining K–12 STEM teachers that can encourage students' future STEM careers plays a role in the digitally-mediated learning space (Leonard, Burrows, & Kitchen, 2019). However, more research in this area is needed.

Gender

When considering the binary gender classification of males and females, more males than females are learning and ultimately working in STEM-related fields (Dasgupta, Scircle, & Hunsinger, 2015; Dowell, Lin, Godfrey, & Brooks, 2019). Recent statistics indicate that the percentage of females in STEM lags behind males. While 52% of the general population is female, in 2016, women comprised only about 20% of students graduating with a bachelor's degree in engineering (NSF, 2019). Where engineering ranks for men and women among major fields of baccalaureate completion provides further evidence that women are lagging behind. Engineering, the second largest field of study for Caucasian and Asian males in 2016, was ranked 18th for all female ethnic populations except Asian (Anderson, Williams, Ponjuan, & Frierson, 2018). Women participating in communities of learning have seen significant increases in retention and graduation in the STEM disciplines over non-participant counterparts (Dagley, Georgiopoulos, Reece, & Young, 2016). For those who do not identify with binary classifications, there are no published statistics. In online collaborations, males and females interact differently, with women engaging in more productive discourse and more productive and dynamic interactions (Lin, Dowell, Godfrey, Choi, & Brooks, 2019).

Neurodiversity

Neurodiversity remains an area with minimal research and support for learners in DMTL. Although work has begun with learners with autism (Cox et al., 2017; see also NSF award nos. 1612009 & 1612090), broadening pathways for learners of all abilities, other research remains limited and unrelated to team learning. Special education and disability services in higher education are often based on a medical model of disability leading to a deficit model that implies that the individual (i.e., learner) needs to be diagnosed, and the problem needs to be fixed or "accommodated" in order to access education. Yet, researchers have identified learning strategies that higher education students with learning differences have found to be useful in learning science (Cox, Ogle, & Campbell, 2019).

Accessibility for Inclusion

For those with hearing, seeing, or mobility impairments, opportunities to access DMTL may be limited to the accessibility technologies that are available for learners to gain access. The lack of assistive technologies has been known to prohibit learners from accessing educational experiences (Koch, 2017). Overcoming these challenges in DMTL environments necessitates planning and partnering with university or college-wide accessibility services. For example, students who are colorblind or have vision or hearing deficits could be empowered to be strong contributors in team environments by virtue of assistive technologies (Ismaili & Ibrahimi, 2016; Lersilp & Lersilp, 2019).

Culture

Students working in culturally diverse groups may have differing learning expectations and the behavioral motives than others in the group (Popov, Biemans, Brinkman, Kuznetsov, & Mulder, 2013; Popov et al., 2012; Popov et al., 2014). To foster intercultural CSCL, dynamic adaptive scaffolding has been recognized as an approach that incorporates machine learning techniques. (Adamson, Dyke, Jang, Rosé, 2014; Gweon, Jain, McDonough, Raj, & Rosé, 2013). Machine Learning techniques are applied to identify potential and actual problems occurring in culturally diverse CSCL groups. By identifying problems within transactivity of talk (i.e., degree to which students refer to each other and build upon each other's contributions during this process) communication can be addressed and increased. Culture can be advantaged by virtue of the way the content is presented. For instance, *Asset-Based Practices in Engineering Design* (APRENDE), an NSF project (EEC 1826354) aims to build culturally sustaining and responsive informal and formal STEM experiences for Latinx students by connecting classroom content within the social, cultural, and historical contexts in which students live (Wertsch, 1998). The project focuses on providing context to make content more relevant as the students culturally relate to the content while collaborating with peers (Passel, Cohn, & Lopez, 2011).

Global Connections

First, these challenges may include communication difficulties from language, culture, and technology differences. Second, the technological access and affordances (e.g., Internet access, software and hardware, and electricity) can be a barrier. Espino, a Co-PI of the International Community for Collaborative Content Creation (IC4), discussed how her project evidenced students working together across five continents in informal learning environments to create STEM-focused digital media artifacts that addressed real-world STEM based projects like poverty and air quality. Although students were motivated to participate in their international collaborations, co-constructing digital artifacts required overcoming basic language barriers and technological tools.

Geographical Inequalities

Geographical inequalities can occur both domestically and internationally. These inequalities can manifest in access, assignment type, or instructional preparation (Herman, Davinia, & Klein, 1996). Baker (2019) at the recent *Learning Analytic and Knowledge Conference* discussed the need to investigate technologies by geographical location, as what works in one geographical location may not work in another.

Further, teams without geographical diversity learning experience may not be as robust as those with greater geographical diversity. Kulkarni, Cambre, Kotturi, Bernstein, and Klemmer (2015) higher geographically diverse discussion had greater learning than those from a more homogeneous geographic background. The differences in opinions expressed based on local geographical contexts were valued over immediate compromises without discussion

Intergenerational and Non-Traditional Students

The growth of non-traditional undergraduate students (National Center for Education Statistics, 2015) and the unique needs of these learners due to their need to balance out-of-school responsibilities (e.g., family, financial, and occupation) provides another type of diversity (Erisman & Steele, 2012). Research is needed related to student teams and non-traditional or intergenerational students. Insights into how their experiences and background affect their group interactions should be considered.

Table 16 shows the current status of research relating to each of the above-mentioned socio-cultural factors.

Table 16

Status of Socio-Cultural Research Related to DMTL

Socio-Cultural Factors	**No Evidence**	**Developing Evidence**	**Foundational (Minimal)**	**Emerging**	**Advanced**
Ethnicity				X	
Gender				X	
Neurodiversity			X		
Accessibility for Inclusion		X			
Culture			X		
Intercultural Global		X			
Geographical	X				
Intergenerational	X				

Note: Developing (at least 1 study), Foundational (at least 10 studies), Emerging (more than 10 less than 25), Advanced (25 or more)

Theme 4B: Fostering Inclusivity through DMTL

- What types of digital learning environments foster inclusivity?
- What type of training is needed for faculty to foster inclusivity in DMTL?
- What type of skills do students need to foster inclusivity with each other?
- How can active learning be fostered among all learners in DMTL?

The Partnership for 21st Century Skills identifies collaboration, communication, critical thinking, and creativity as skills that are needed and necessary for success in future work environments. Although students may work alone in digital spaces (Borowczak & Burrows, 2019), all of these foundational skills have been identified as outcomes of team interactions (Theobald, Eddy, Grunspan, Wiggins, & Crowe, 2017). However, minoritized participants may not contribute to the same level as non-minoritized team members. It is incumbent on educators and researchers to recognize this incongruence and to investigate solutions that could promote student- and instructor-facing solutions to mitigate interaction deficits.

Culturally-Relevant Pedagogy

Culturally-relevant pedagogy, when employed (Ladson-Billings, 1995a, 1995b), provides a transformative approach to challenge educators thinking about students' individual deficiencies as the cause for limited learning (Valencia, 1997). When educational opportunities are designed and structured to incorporate culture-relevant pedagogies, research shows that learning improves (Aronson & Laughter, 2016). Incorporating the foundational ideologies of Gay (2013), Siwatu (2007), and others (Lee, 1998; Mejia, 2018; Nieto, 2010; Tatum, 2000) both in the classroom and in tools utilized in developing and mediating digital teamwork may contribute to more culturally diverse teams. Steps to incorporate these practices with students necessitates both instructor and tool developer training in this framework (Bandura, 1997; Gay 2013; Pajares, 2003).

Universal Design for Learning

Universal Design for Learning (UDL) approach to learning serves as a framework for designing instruction and learning tools to make learning accessible to all learners (Hollingshead, 2018). UDL leverages learning technologies to aid learners who may need varying modifications and accommodations (Schreffler, Vasquez, Chini, & James, 2019). Further, UDL considers the principles of learning sciences (Rose & Meyer, 2006). Tools, curriculum, and pedagogy that incorporate a UDL approach are characterized by providing multiple pathways to meet the needs and challenges of all learners (Hall, Meyer, & Rose, 2012).

Learner Anonymity

In online learning environments there are several ways that a digital learning environment may identify a person to all users. For some programs, users' first and last name may be automatically shared with other users, while other programs allow users to identify themselves by a pseudonym. Personal avatars or images add another complexity for self-identity. Although some may want to use their own image, others may consider the image of themselves to create a barrier or advantage (Groom, Bailenson, & Nass, 2009). Although some students prefer to remain anonymous in online contexts (Devaraj, Alfred, Madathil, & Gramopadhye, 2015), others may not want to interact with those who do not self-identify (Kang, Brown, & Kiesler, 2013). The reluctance to engage in online team discourse may be related to self-protection from bias (Nilizadeh et al., 2016).

Privacy concerns abound in team learning. Learners may be fine with their learning activities being analyzed to help them optimize their learning or to prevent dropout. However, some students prefer that their learning activities not be used to be compared to other students (Arnold & Sclater, 2017). There is a delicate balance between the benefits of learning analytics, anonymity, and respecting privacy. Creating a safe space in a digitally-mediated learning environment can be complex. It remains an issue to be explored through research and practice.

Soft Skills

Understanding the role of one's sociocultural background is pivotal in productive and effective team learning. Developing interpersonal skills while working in STEM content can be developed before a person enters the workforce. Valuing the sociocultural differences and developing an understanding of each other may contribute to the retention and achievement of traditionally underrepresented groups in STEM.

In DMTL, soft skills include communication, cooperation, and collaboration needed to communicate and navigate team dynamics (Burrows & Borowczak, 2019; Burrows & Harkness, 2016). Cooperation and collaboration often go hand in hand for effective communication to take place. The opposite of these positive characteristics are incivility and conflict. Academic incivility moves beyond civil discourse to discourteous actions including: (a) lurking, (b) failure to respond or failure to respond in a timely manner (Clark, Werth, & Ahten, 2012), and (c) trolling (Carr, Zube, Dickens, Hayter, & Barterian, 2013). Developing collaborative skills can provide a foundation so students can: (a) craft purposeful communication, (b) become active and empathetic listeners, and (c) contribute to shared expectations (Campbell, Tinstman Jones, & Lambie, 2019).

Active Learning

Active learning moves the learner from a passive role of listening to information to an active role of participating. In a DMTL environment, students actively interact with content and each other to develop knowledge. Students realize achievement gains when participating in an active learning approach. For example, Snyder, Sloane, Dunk, and Wiles's (2016) use of Peer-Led Team Learning in an introductory biology course produced greater achievement for all students and a "drastic reduction in the failure rate" (p. 1) of underrepresented minority students, when compared with traditional lecture instruction.

Theme 4C: Equity and Diversity

- What are examples of existing DMTL technologies to improve equity among all learners?
- What considerations need to be addressed in these existing technologies to provide an equitable digital learning environment?

Existing Tools to Foster Inclusivity

Current tools for creating equitable groups may be available as open source or commercial tools. Tools can be as simple as a spreadsheet like Grumbler (Group Rumbler) that calculates maximized diversity based on the instructor-established criteria (Houston, 2011; Sparrow, 2019). More sophisticated tools, such as SAGLET, use machine learning to provide live real time data. The Scaffolding Agent (SA) that monitors and prompts positive collaborative behaviors considers inclusivity of all members.

SA, a cloud-based computational tool, monitors student psychophysiological inputs (e.g. facial expressions, eye gaze) as well as keystrokes, and verbal conversations through the analysis of automated speech recognition technology. SA prompts members on an as-needed basis to promote transactive discourse and/or get the team member(s) back on track. For example, if SA decides that Student *X* in a Group *Y* has been inactive for a period of time (e.g. lack of interaction, and or no speaking), SA prompts the student with a message (e.g., “your group could use your input”—to Student *X* directly).

Likewise, Tandem offers teamwork lessons and personalized coaching (ECoach) for effective team membership when working on projects. While SA uses machine learning to prompt member participation, Tandem relies on regular check-in surveys (Derry, 2019) to provide feedback on progress and team behaviors. These real-time perspectives can be monitored by the instructor as well.

There are multiple online tools that contribute to team formation, dynamics, interactions, and learning analytics. However, most tools do not specifically address all areas of sociocultural inclusivity and further do not have an educator feedback mechanism to ensure learner agency and autonomy. Further, even with tools that consider team formation and machine learning for instructor feedback, caution should be exercised in relationship to equitable algorithms and programming. Programs that require gender identification or images to be transparent to other learners may contribute to biases (Palomares & Lee, 2010)

LMSs

Most universities utilize LMSs that need further development to meet the needs of students engaged in DMTL environments (Gillett-Swan, 2017; Obizoba, 2016). Shared collaboration spaces, research, and infrastructure of seamless solutions to facilitate DMTL remain a need. Ideas to develop seamless solutions include incorporating expanded workspaces, providing personalized adaptive feedback, student-driven personalized affective team dashboards, and teaming tools for faculty and students.

Challenges in DMTL Related to Equity

Challenges facing learning scientists in DMTL span from human interactions (affective and communication) to technological supports (inequity in technological supports, and access). Barriers for equitable access includes: (a) research and dissemination, (b) beliefs regarding technologies, and (c) human behaviors. More research and its dissemination is needed to enable actionable knowledge for improving teaching and learning environments. Without research, educators in STEM will not have evidenced-based practices to follow to improve equitable teaching and learning. Further the belief that learners are automatically connected by virtue of technology can be misleading as technology is not the bridge to cultural connections (Fussell & Setlock, 2014).

Challenges for students as team members include the level of engagement in collaborations (Fischer, Killar, Stegmann, & Wecker, 2013, p. 57). Likewise, the coordination of different attitudes, styles of communication, and patterns of behaving may negate powerful discourse and interactions (MacLeod, Yang & Xiang, 2017; Uzuner, 2009). Further, instructors may not realize in real-time how these social dynamics are impacting the team, creating a missed opportunity for learning and collaboration.

Self-identity, preconceptions, biases, and status are at the foundation of human interactions. Overcoming bias of other team members, addressing self-identity, and empowering agency are a few of the affective and communication challenges in a DMTL environment. Learner engagement and personal motivation to participate in online group dynamics are often governed by prior experiences in team learning. Negative prior group experiences may contribute to students being hesitant to fully participate in group interactions.

Theme 4D: Transferability and Sustainability of DMTL

- What research topics could be conducted to promote transferability and sustainability of inclusivity in DMTL?
- What research methodologies could be considered to investigate issues of inclusivity?
- Are there ways to contribute to learners' efficacy in DMTL?

With multiple advances in "theory, computational linguistics, and educational technologies", the field of DMTL is at an intersection to advance knowledge and practice, "enabling new kinds of personalized interventions focused on increasing inclusivity and equity" (Goldstone & Lupyan, 2016; Paxton & Griffiths, 2017).

Research

Research related to DMTL and team members primarily focuses on culturally homogenous groups of learners. New lines of research could broaden knowledge related to some of the aforementioned sociocultural groups in digital collaborative learning. The following research questions are representative of explorations for new knowledge that could promote inclusivity approaches and practices.

- How do learners of certain sociocultural groups collaborate to build knowledge?
- What strategies are most helpful in developing teachers' understanding and elicitation of students' funds of knowledge when they engage them in collaborative learning?
- How do learners perceive their and others' behavior in culturally mixed groups of learners?
- How can we facilitate mixed groups by making learners aware of specific pitfalls and misconceptions or by guiding them towards a shared discourse culture?

Action Research

Social psychologist Kurt Lewin (1946) provided the foundation for action research (AR), describing it as a style of research that moves beyond "basic social research" to investigate the background, nature, and impact of social action. AR methodology allows researchers to investigate and further practical solutions that can create positive social, political, and environmental changes in order to establish and strengthen international and interdisciplinary bonds (Burrows, 2019; Burrows & Borowczak, 2019). The framework of AR pairs reflection with action to bring about change and emphasizes consideration and inclusion of diverse perspectives to co-create knowledge through mutual understanding. Action research values the voice of all stakeholders (Schwortz, Burrows, & Guffey, 2017).

Methodologies for the Analysis and Development of Inclusivity Knowledge

Machine Learning and Data Analytic Advancements.

Wise (2019a) expounded on the need to pursue new computational approaches to support learners through integrated analytic feedback at the individual, group, and collective levels. Machine learning can analyze interactions to better understand if inclusivity and equity are evident.

Discourse Analysis.

Discourse analysis involves exploring written or spoken language and often relates to meaning instead of grammar use (Salkind, 2010). There are some studies showing that even the syllabi that are used can impact student perceptions (Parson, 2016; Savaria & Monteiro, 2017). Other studies show that there are some effective means to measure communication in teams, but they are not used as frequently as needed (Borowczak, 2015; Borowczak & Burrows, 2016; Simpson, Clemens, Kinningsworth, & Ford, 2015). Thus, what STEM educators at all levels do and say can impact DMTL spaces. Further research, specifically focusing on discourse analysis, could inform the DMTL space for optimal student achievement and instructor encouragement.

Potential Idea: A Communication Hub.

Future possibilities in teaming might include developing a real time communication hub to consider the affective aspects of teaming accessible to the instructor and team members. Beyond a typical dashboard, students might have an option of hovering over a team members' name or icon that provides real-time analytics of how the member was feeling at the moment emotionally about the work. Further, a student would have the ability to choose how and to what degree they wanted to identify to their team members. For instance, if a team member chooses anonymity, the team member could choose an anonymous icon to represent themselves with their digital team or course. Student/team members could disclose other items and change the degree of disclosure based on their preference. These affective status updates may help to provide valuable information as it relates to student and team performance.

Potential Inventories: Beyond Demographics.

How can students move themselves forward to interact in STEM environments when they do not feel comfortable or lack the content knowledge to interact with others in STEM environments and the instructor is unaware of these barriers? Pre-content knowledge assessment would help instructors identify students who need scaffolding and remediation. Students can be provided resources to fill in the knowledge gap. Further, students could be grouped in such a way that content deficiencies are redressed and remedied. By identifying students with content deficits instructors can provide solutions to alleviate negative perceptions that students may have regarding participating in group environments.

Another possible idea is to consider the expectations of diversity that exists between learners. The notions and nuances of students' communication styles and behaviors are important elements in group dynamics. Student perceptions related to outcomes could be considered by completing a goals and outcomes inventory. Students with shared expectations would be paired into homogeneous teams based on shared learning goals and expected outcomes.

Students might complete an inventory of their course expectations (outputs) and their willingness to contribute (inputs). Other inputs might include: (a) the times of the week they are available, (b) their intended behavior regarding completing assignments early or right before the deadline, and (c) their preferred modes and times of communication. Shared expectations regarding contributions and outcomes may contribute to a robust learning experience.

Theme 4E: Future possibilities for inclusivity and equity building in DMTL

- What are the 1, 3, and 5+ year research, development, and implementation goals of DMTL?
- What resources (financial and human) may be needed to support these needs?

Although discussing and exploring broadening inclusivity in teaming was the goal of the workshop, it was clear that additional foundational work related to understanding the intersectionality of diversity remains a necessity. Foundational themes appear in plans for one and three years, and in the five year section the suggestions are contingent on foundational themes being addressed.

Possible objectives for research and funding +1, +3, +5 years

1-year research objectives

Many digital environments and DMTL-type projects are focused on certain communities and populations (Hollingshead & Carr-Chellman, 2019). Because there is a general sense that there is a lack of strong examples of all-inclusive digital environments, initial research projects and objectives could evaluate the perceived and known inclusivity of digital team learning environments.

The following research areas, needs, and questions were suggested to be evaluated in the next one year as it relates to inclusive cyberlearning.

1. Define inclusivity. Expand definitions that define factors that exclude any individual from the learning community.
2. Develop a glossary of common inclusivity terms for faculty and students (a common language) for digitally-mediated environments (Wise & Schwartz, 2017).
3. Identify ways to quantify inclusivity.
4. Establish and assess programs with the specific goal to change the culture both quantitatively and qualitatively.
5. Incorporate curricular discussions with all students to define and address inclusivity within the specific learning community.
6. Engage and equip students and faculty to address marginalization issues through affective and digital means.
7. Develop programs in teacher education that consider the intersectionality of marginalization.
8. Train faculty in student identity.
9. Test interventions to mitigate bias, including learners': (a) sense of belonging, (b) STEM identity, and (c) motivation.
10. Identify interventions from cross-curricular perspectives related to inclusivity (e.g., psychology, group dynamics, communication, and special education).
11. Assess the degree to which faculty and students understand and address inclusivity within DMTL and STEM environments.

12. Consider curriculum such as UDL in digital STEM environments for inclusivity purposes.
13. Identify the characteristics of inclusive teams.

3-year research objectives

Building on the 1-year foundation suggested above, the following provides a pathway towards understanding ways to embed and train for inclusivity within STEM digitally mediated learning.

1. Create automated, scalable methodologies to quantify and increase inclusion in DMTL environments. These may include pyschophysiological, self-report mechanisms, and inventories.
2. Discover ways to increase all populations' representation in STEM environments to build more robust digitally mediated teams.
3. Expand analysis of communication for coded language.
4. Develop policies and procedures to mitigate coded language, selection bias, and incivilities.
5. Increase technological equity for all students currently marginalized beyond geographical restrictions (e.g., using Google Cardboard instead of Oculus Rift or Magic Leap).
6. Develop and assessing safe environments.
7. Develop training for faculty for an inclusivity mind shift to reduce marginalization.
8. Build on coaching app like Tandem or CATME.
9. Multi-institutional grants to develop a database to house DMTL STEM datasets on underrepresented individuals engaging in team learning (e.g., Discourse DB)—to allow us (interdisciplinary research teams) to share and explore students' lived experiences across STEM disciplines.
10. Develop a feedback mechanism that reports the neurological, social, cognitive, and affective experience in real time for group cohesion.
11. Develop action research projects that engage all stakeholders (students, faculty, education, and industry) to measure real-time DMTL contributions.
12. Design funding opportunities that consider infrastructure to avoid piecemeal solutions.
13. Investigate levels of motivation, engagement, and commitment to participate in team learning in STEM.
14. Investigate interventions to assess and improve educators' skills for inclusivity both in higher education and in K–12.
15. Develop machine learning to investigate an assets approach to team building versus a deficits approach.

5+ year research objectives

The following section outlines the five year and beyond plan, which is contingent on items from Years 1–3 being addressed.

1. Develop technological affordances that help students self-define with flexibility promoting a safe learning environment.
2. Investigate strategies that promote autonomy and agentic behaviors.
3. Explore how learners perceive their and others' behavior in socioculturally diverse groups of learners.
4. De-emphasize special education in favor of personalized and customizable education.
5. Develop informational overviews that include separate but related disciplines (e.g., terminology use) that directly impact this type of work and include the stakeholders in the work (e.g., include in-service teachers in

the research team if the work is studying in-service teacher use/work).

6. Utilize AR methodology; look at the Accreditation Board for Engineering and Technology's "soft skills" from engineering education as a 21st-century skill set base.
7. Develop curriculum to facilitate diverse group communication and culture by making learners aware of specific pitfalls and misconceptions or guiding them toward a shared discourse culture.
8. Design collaborative environments that support inclusivity.
9. Define pedagogies and ecologies that support inclusivity.
10. Create an app to scaffold and support faculty when working with students who have an identified neurodiversity.
11. Investigate the hidden curriculum biases of digital teaming programs.
12. Develop realistic real-world scenarios that support sociocultural groups.
13. Contribute to a mechanism for international and interdisciplinary partnerships.
14. Reimagine funding mechanisms and their impact on research—instead of incremental funding, consider sustainable metrics for 5–8 or even 10-year funding to allow for research that is cohesive, coherent, and broadly impactful.

Conclusion

The Track 4 discussion on DMTL has provided information regarding sociocognitive factors of learning related inclusivity and equity. Current perspectives and future directions have indicated that DMTL would benefit from interdisciplinary investigations that included Learning Scientists, STEM Educators, Computer Scientists, and STEM Content Experts. These interdisciplinary teams could re-engineer current technologies and develop new ecologies and environments that would contribute to broadening and sustaining participation in STEM without biases.

While new tools and ways to analyze resulting data are important aspects of broadening pathways in STEM, the human factor cannot be ignored. Training for instructors may result in reduced bias and more equitable learning. Embedding and fostering positive social skills in team learning could support students in the short term (classroom learning) and in the long term with skills that students will use beyond the classroom in their future STEM careers.

Chapter Contributors:

Laurie O. Campbell, University of Central Florida
Andrea Burrows, University of Wyoming
Melissa Dagley, University of Central Florida
Nia Dowell, University of Michigan
Danielle Espino, Pepperdine University
Jennifer Katz, University of Central Florida
Jessica Tinstman Jones, University of Central Florida
Vitaliy Popov, University of San Diego
Gloria Niles, University of Hawaii West Oahu
Stacy Watkins, University of Central Florida

Chapter Editors:

Laurie O. Campbell
Andrea Burrows
Melissa Dagley
Gloria Niles
Stacy Watkins

Chapter 7

Concluding Remarks

This White Paper responds to the driving question: "Which research will advance effective and scalable digital environments for synchronous team-based learning involving problem-solving and design activities within Grades 6–20 STEM classrooms for all learners?" Addressing this question encompasses the detailed identification of research objectives feasible to initiate immediately (within 1 year), in the near term (within 3 years) and the long term (5 or more years) along four parallel tracks:

Track 1: Facilitating Team Learning in Real-time via Online Technologies
Track 2: Personalizing Collaborative Learning through Analytics
Track 3: Supporting Digital Teams using Active Pedagogical Strategies
Track 4: Empowering Equitable Participation

A concluding summary of prominent research recommendations from each track is listed in Table 17.

Table 17

Summary of Top-Level Research Recommendations

Track	1-Year Research	3-Year Research	5+ Year Research
1. Tools for DMTL	• Survey students on which widgets/features they most value in student-facing interfaces. • Conduct a multi-institution survey or workshop to determine consensus on essential features of an instructor-facing dashboard for DMTL frameworks. • Conduct a multi-institutional survey to reach consensus on a set of standards for DMTL.	• Develop STEM-specific platforms beyond plain text collaboration to include equations, graphics and digital objects. • Design new instructor dashboards based on survey consensus. • Develop a set of design elements for an immersive VR environment.	• Extend instructor-facing platforms with AI-based data collection and feedback systems, together with mechanisms for capturing longitudinal growth together with situational single-class learning gains. • Apply and extend AI technologies to adapt the XR environment to increase learning including auto-insertion of virtual students with teams, possibly triggered by stagnation of progress or retreading the same ground.

			• Extend DMTL clearinghouses to allow for new approaches to data collection, management, and analytics.
2: Analytics for DMTL	• Develop standards for data collection and reporting regarding DMTL. • Identify best practices to providing feedback based on formative assessment data. • Determine optimal ways of aligning cognitive demands of learning tasks with student abilities.	• Develop tools to capture learner data in a minimally obtrusive manner. • Identify techniques that can be used to automate productive feedback based on student and team data. • Develop ways of placing appropriate scaffolds in a team learning exercise without reducing cognitive demand.	• Develop tools (including AI) that facilitate and accelerate feedback across varying dimensions of team learning. • Implement data analysis techniques appropriate for large-scale, noisy data. • Develop real-time data analysis tools for evaluation of team efficacy.
3: Pedagogy of DMTL	• Explore the effectiveness of short-term professional development opportunities for faculty to learn to use analytics to manage and evaluate team processes. • Develop best practices and implementation strategies for XR (extended reality: virtual, mixed and augmented reality) and other DMTL technologies. • Measure the effectiveness of varied approaches of team formation, peer evaluation, and/or peer feedback.	• Explore models of cultivating a culture of accountability within student life as opposed to a culture of policing. • Build and test prototype XR (VR, AR and MR) for STEM content. Identify unexpected issues and challenges. Fully explore instructor training needs. Assess perceptions of learning, engagement and actual learning. • Incentivize collaborations between learning sciences experts and subject-matter experts. • Examine approaches to prepare STEM faculty/teachers to support student-centered DMTL	• Unpack interdisciplinary approaches that focus on team management. • Identify best practices for building team accountability. Develop and measure the effectiveness of accountability tools. • Create a virtual innovation center that houses high-impact practices and a repository of resources.

4. Equitable Participation in DMTL	• Identify ways to quantify inclusivity. • Define inclusivity. Expand definitions that define factors that exclude any individual from the learning community. • Develop a glossary of common and cross-cutting inclusivity terms for faculty and students (a common language) for DMTL. •	• Arrange for multi-institution cooperation to develop a database to house DMTL STEM datasets (quantitative and qualitative) of underrepresented individuals, teams, and groups engaging in team learning (e.g., Discourse DB) for interdisciplinary research teams to share and explore students' experiences across STEM disciplines. • Create automated, scalable methodologies to quantify and increase inclusion in DMTL environments. These may include pyschophysiological, self-report mechanisms, and inventories. • Investigate how learners of certain sociocultural groups collaborate to build knowledge.	• Develop realistic real-world scenarios that support diverse sociocultural groups. • Contribute to a mechanism for international and interdisciplinary partnerships.

Based on the detailed discussions within each track, there emerged several crosscutting Immediate ***(Imm)***, Near-Term ***(NT)***, and Longer Term ***(LT)*** recommendations for future research, which are highlighted below:

Imm: Unify research evidence on efficacy of *real-time classroom-based DMTL across delivery modalities* (e.g., co-located, synchronous-but-seated-separately, and mobile-devices) via studies and workshops.

Imm: Assemble *glossary of inclusivity terminology, methods, and metrics* relevant to DMTL. Consider potential advances in equitable participation across the range of interactions enabled within digital teams.

NT: Create *reusable and adaptable DMTL activities with engaging learner interface*s supporting STEM-specific tools (e.g., models, programming, equations, simulations) while employing *analytics for personalization and instructor orchestration of cooperative learning in real-time*.

NT: Create a *Virtual Innovation Center* showcasing high-impact DMTL practices, users, and an adaptable resource repository that leverages methodologies emphasizing interdisciplinary pyschophysiological efforts, self-report mechanisms, and inventories to advance inclusivity.

LT: Design *new data science approaches exploring various team formations'* impact on learning outcomes.

LT: Apply and extend *machine learning and AI technologies within DMTL* to: (a) longitudinally suggest (or automatically construct) team learning activities personalized to the learners at-hand, (b) hybridize DMTL with Intelligent Tutoring Systems (ITS) whereby ITS agents have co-instructor roles, and (c) adapt the XR environment to spontaneously insert virtual teammates at pivotal moments (e.g., triggered by retreading the same ground or persisting on a wrong path).

Overall, discussions within each track led to a similar research flow consisting of establishing standards/best practices in the immediate term, followed by development of tools, models, and methodologies in the near-term, and finally extension of these tools/models/methodologies (e.g., using emerging technologies such as XR/AI) in the long term. It is the collective objective of the contributors that beyond these capstone findings themselves, the detailed outcomes and citations summarized in this White Paper can provide a unified compendium for future research in DMTL.

References Cited

A

Adams, D. M., Mayer, R. E., MacNamara, A., Koenig, A., & Wainess, R. (2012). Narrative games for learning: Testing the discovery and narrative hypotheses. *Journal of Educational Psychology*, *104*(1), 235–249.

Adamson, D., Dyke, G., Jang, H., & Rosé, C. P. (2014). Towards an agile approach to adapting dynamic collaboration support to student needs. *International Journal of Artificial Intelligence in Education*, *24*(1), 92–124.

Alexander, B., Ashford-Rowe, K., Barajas-Murph, N., Dobbin, G., Knott, J., McCormack, M., . . . Weber, N. (2019). *EDUCAUSE Horizon Report 2019 Higher Education Edition*. Louisville, CO: EDUCAUSE.

Ambrose, S. A., Lovett, M., Bridges, M. W., DiPietro, M., & Norman, M. K. (2010). *How learning works: Seven research-based principles for smart teaching*. San Francisco, CA: Jossey-Bass.

Anderson, J., Rainie, L., & Luchsinger, A. (2018). Artificial intelligence and the future of humans. *Pew Research Center*. Retrieved from http://www.pewinternet.org/2018/12/10/artificial-intelligence-and-the-future-of-humans/

Anderson, E. L., Williams, K. L., Ponjuan, L., & Frierson, H. (2018). The 2018 status report on engineering education: A snapshot of diversity in degrees conferred in engineering. Association of Public & Land-Grant Universities: Washington, D.C.

Annamma, S. & Morrison, D. (2018). Identifying dysfunctional education ecologies: A DisCrit analysis of bias in the classroom. *Equity & Excellence in Education, 51*(2), 114–131. doi:10.1080/10665684.2018.1496047

Arnold, K. E., & Sclater, N. (2017, March). Student perceptions of their privacy in learning analytics applications. *Proceedings of the Seventh International Learning Analytics & Knowledge Conference*. Association for Computing Machinery, Vancouver, BC, Canada. doi:10.1145/3027385.3027392

Aronson, B., Laughter, J. (2016). The theory and practice of culturally relevant education: A synthesis of research across content areas. *Review of Educational Research, 86*(1), 163–206. doi:10.3102/003465431558206

Awedh, M., Mueen, A., Zafar, B., & Manzoor, U. (2015). Using Socrative and smartphones for the support of collaborative learning. *International Journal on Integrating Technology in Education, 3*(4), 17–24.

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators & Virtual Environments*, *6*(4), 355–385.

Azzam, A. (2016). Six strategies for challenging gifted learners. *Education Update*, *58*(4), 2–14.

B

Baker, R. S. J. D, & Yacef, K. (2009). The state of educational data mining in 2009: A review and future visions. *Journal of Educational Data Mining*, *1*(1), 3–17.

Baker, R. (2019). *Some challenges for the next 18 years of learning analytics.* Keynote address: *Learning Analytic and Knowledge Conference*. Tempe, AZ.

Bannan, B., Gallagher, S., & Lewis, B. (2017). Next Generation Learning – Smart Medical Team Training. *Internet of Things and Data Analytics Handbook*, Hoboken, NJ: John Wiley and Sons. 95–105.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York, NY: W. H. Freeman.

Bani-Hani, E., Al Shalabi, A., Alkhatib, F., Eilaghi, A., & Sedaghat, A. (2018). Factors affecting the team formation and work in Project Based Learning (PBL) for Multidisciplinary Engineering subjects. *Journal of Problem Based Learning in Higher Education*, *6*(2), 136–143.

Barkley, E. F., Cross, K. P., & Major, C. H. (2014). *Collaborative learning techniques: A handbook for college faculty*. Hoboken, NJ: John Wiley & Sons.

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education*. New York, NY: Springer.

Basoglu, K. A., Fuller, M. A., & Valacich, J. S. (2012). Enhancement of recall within technology-mediated teams through the use of online visual artifacts. *ACM Transactions on Management Information Systems (TMIS), 3*(1), 2.

Belbin, R. M. (2012). *Team roles at work*. Abingdon, Oxon, UK: Routledge.

Bell, P., Stromholt, S., Neill, T., & Shaw, S. (2017). Making science instruction compelling for all students: Using cultural formative assessment to build on learner interest and experience. *OER Professional Development Session from the ACESSE Project.* Retrieved from http://stemteachingtools.org/pd/sessionc

Belland, B. R., Glazewski, K. D., & Ertmer, P. A. (2009). Inclusion and problem-based learning: Roles of students in a mixed-ability group. *RMLE Online*, *32*(9), 1–19.

Bishop, J. L., & Verleger, M. A. (2013, June). The flipped classroom: A survey of the research. *American Society for Engineering Education Annual Conference & Exposition.* Atlanta, GA.

Bodemer, D., & Dehler, J. (2011). Group awareness in CSCL environments. *Computers in Human Behavior*, *27*(3), 1043–1045.

Borowczak, M. (2015). Communication in STEM education: A non-intrusive method for assessment & K20 educator feedback. *Problems of Education in the 21st Century*, *65*, 18–27.

Borowczak, M., & Burrows, A. C. (2016). Enabling collaboration and video assessment: Exposing trends in science preservice teachers' assessments. *Contemporary Issues in Technology and Teacher Education*, *16*(2), 127–150.

Borowczak, M., & Burrows, A. C. (2019). Ants go marching—Integrating computer science into teacher professional development with NetLogo. *Education Sciences, 9*(1), 66. doi:10.3390/educsci9010066

Borrego, M., Froyd, J. E., & Hall, T. S. (2010). Diffusion of engineering education innovations: A survey of awareness and adoption rates in US engineering departments. *Journal of Engineering Education*, *99*(3), 185-207.

Borrego, M., & Henderson, C. (2014). Increasing the use of evidence-based teaching in STEM higher education: A comparison of eight change strategies. *Journal of Engineering Education*, *103*(2), 220-252.

Botha, A., Steyn, R., Weilbach, L., & Muller, E. (2018, August). Using the iPeer LMS feature to evaluate peer participation in teamwork for assessment "as learning": Lessons learned. *International Symposium on Emerging Technologies for Education* (pp. 46-55). New York, NY: Springer.

Buck Institute for Education PBLworks. (2019). *What is PBL?* Retrieved from https://www.pblworks.org/what-is-pbl

Bush, M. E. L. (2004). *Breaking the code of good intentions: Everyday forms of whiteness*. Lanham, MD: Rowman & Littlefield.

Burrows, A. C. (2019). US Perspectives on action research in education. In *The Wiley Handbook of Action Research in Education*. doi:10.1002/9781119399490.ch4

Burrows, A. C., & Borowczak, M. (2019). Computer science and engineering: utilizing action research and lesson study. *Educational Action Research*, 1-16.

Burrows, A. C., & Harkness, S. S. (2016). Experiencing action evaluation's cyclic process: partnering conflict, reflection, and action. *Educational Action Research*, *24*(4), 460-478.

Brown, R., Brown, J., Reardon, K., & Merrill, C. (2011). Understanding STEM: Current perceptions. *Technology and Engineering Teacher; Reston*, *70*(6), 5–9.

C

Campbell, L.O., Tinstman Jones, J. L., Lambie, G. W. (Under Review). Promising practices for addressing academic incivility in online higher education.

Cardador, M. T., Northcraft, G. B., & Whicker, J. (2017). A theory of work gamification: Something old, something new, something borrowed, something cool? *Human Resource Management Review*, *27*(2), 353-365.

Carr, C. T., Zube, P., Dickens, E., Hayter, C. A., & Barterian, J. A. (2013). Toward a model of sources of influence in online education: Cognitive learning and the effects of Web 2.0. *Communication Education, 62*(1), 61-85. doi:10.1080/03634523.2012.724535

CAST (2018). *Universal Design for Learning Guidelines version 2.2*. Retrieved from http://udlguidelines.cast.org

Center for Curriculum Redesign. (2019). *Artificial intelligence in education: Promises and implications for teaching and learning*. Milton, MA: Center for Curriculum Redesign.

Chiu, M. M. (2008). Flowing toward correct contributions during group problem solving: A statistical discourse analysis. *The Journal of the Learning Sciences, 17*(3), 415-463.

Chiu, M. M., & Lehmann-Willenbrock, N. (2016). Statistical discourse analysis: Modeling sequences of individual actions during group interactions across time. *Group Dynamics: Theory, Research, and Practice, 20*(3), 242.

Clark, M., Merrick, L. C., Styron, J., Dolowitz, A., Dorius, C., Madeka, K., Bender, H.,... Winter, L. (2018). Off to on: Best practices for online Team-Based Learning™. *Center for Excellence in Learning and Teaching Publications, 1*.

Clark, C. M., Werth, L., & Ahten, S. (2012). Cyber-bullying and incivility in the online learning environment, part 1: Addressing faculty and student perceptions. *Nurse Educator 37*(4), 150-156. doi:10.1097/NNE.0b013e31825a87e5

Collins, A. (1991). Cognitive apprenticeship and instructional technology. In L. Idol & B. F. Jones (Eds.), *Educational values and cognitive instruction: Implications for reform* (pp. 121-138). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Corbo, J. C., Reinholz, D. L., Dancy, M. H., Deetz, S., & Finkelstein, N. (2016). Framework for transforming departmental culture to support educational innovation. *Physical Review Physics Education Research*, *12*(1), 010113.

Cooper, G., & Thong, L. P. (2018). Implementing virtual reality in the classroom: Envisaging possibilities in STEM education. *STEM Education: An Emerging Field of Inquiry* (pp. 61-73). Leiden, NL: Brill Sense.

Cooper, M. M., & Stowe, R. L. (2018). Chemistry education research: From personal empiricism to evidence, theory, and informed practice. *Chemical Reviews*, *118*, 6053-6087.

Cortright, R. N., Collins, H. L., & DiCarlo, S. E. (2005). Peer instruction enhanced meaningful learning: ability to solve novel problems. *Advances in physiology education*, *29*(2), 107-111.

Cox, B. E., Thompson, K., Anderson, A., Mintz, A., Locks, T., Morgan, L., ... Wolz, A. (2017). College experiences for students with Autism Spectrum Disorder. *Journal of College Student Development, 58*(1), 71-87.

Cox, T., Ogle, B. & Campbell, L. O. (2019). Investigating challenges and preferred instructional strategies in STEM. *The Journal of Postsecondary Education and Disability, 32*(1). ISSN: 2739-7762.

Coyne, L., Merritt, T. A., Parmentier, B. L., Sharpton, R. A., & Takemoto, J. K. (2019). The past, present, and future of virtual reality in pharmacy education. *American Journal of Pharmaceutical Education*, *83*(3), 281-290.

Coyne, L., Takemoto, J. K., Parmentier, B. L., Merritt, T., & Sharpton, R. A. (2018). Exploring virtual reality as a platform for distance team-based learning. *Currents in Pharmacy Teaching and Learning*, *10*(10), 1384-1390.

Currey, J., Sprogis, S., Burdeu, G., Considine, J., Story, I., Gentle, A., Graan, S., Hewitt, N. & Oldland, E. (2019, March). *Digital Capture of Active and Collaborative Learning: A feasibility study.* Poster presented at the annual meeting of the Team-Based Learning Collaborative, Tampa, FL.

D

Dagley, M., Georgiopoulos, M., Reece, A., & Young, C. (2016). Increasing retention and graduation rates through a STEM learning community. *Journal of College Student Retention: Research, Theory & Practice, 18*(2), 167-182. doi:10.1177/1521025115584746

Dale, R., Fusaroli, R., Duran, N. D., & Richardson, D. C. (2013). The self-organization of human interaction. *Psychology of Learning and Motivation - Advances in Research & Theory, 59*, 43-95. doi:10.1016/B978-0-12-407187-2.00002-2

Danish, J. A., Enyedy, N., Saleh, A., Lee, C., & Andrade, A. (2015). Science through technology enhanced play: Designing to support reflection through play and embodiment. *International Society of the Learning Sciences, Inc. [ISLS], 1*.

Dasgupta, N., Scircle, M. M., & Hunsinger, M. (2015). Female peers in small work groups enhance women's motivation, verbal participation, and career aspirations in engineering. *Proceedings of the National Academy of Sciences*, *112*(16), 4988-4993.

Dede, C. (2016). Social media and challenges to traditional educational models. In C. Greenhow, J. Sonnevend, & C. Agur (Eds.), *Education and Social Media: Toward a Digital Future,* (pp. 95-112). Cambridge, MA: MIT Press.

Dede, C., Grotzer, T. A., Kamarainen, A., & Metcalf, S. J. (2017). Virtual reality as an immersive medium for authentic simulations. *Virtual, Augmented, and Mixed Realities in Education* (pp. 133-156). Singapore, HK: Springer.

Dede, C. J., Jacobson, J., & Richards, J. (2017). Introduction: Virtual, augmented, and mixed realities in education. In *Virtual, Augmented, and Mixed Realities in Education* (pp. 1-16). Springer, Singapore.

DeHaan, R. L. (2005). The impending revolution in undergraduate science education. *Journal of Science Education and Technology*, *14*(2), 253-269.

DeLiema, D., Saleh, A., Lee, C., Enyedy, N., Danish, J., Illum, R., ... Mahoney, C. (2016). Blending play and inquiry in augmented reality: A comparison of playing a video game to playing within a participatory model. Singapore: *International Society of the Learning Sciences.*

Dellos, R. (2015). Kahoot! A digital game resource for learning. *International Journal of Instructional Technology and Distance Learning*, *12*(4), 49-52.

DeMara, R. F., Chen, B., Hartshorne, R., & Thripp, R. (2017). Elevating participation and outcomes with computer-based assessments: An immersive development workshop for engineering faculty. *ASEE Computers in Education Journal*, *8*(3), 1-12.

DeMara, R. F., Salehi, S., Hartshorne, R., & Chen, B. (2017, June). GLASS: Group Learning At Significant Scale via WiFi-enabled learner design teams in an ECE flipped classroom. In *Proceedings of American Society for Engineering Education Annual Conference & Exposition* (pp. 12957-12974). Columbus, OH.

DeMara, R. F., Sheikhfaal, S., Wilder, P. J., Chen, B., & Hartshorne, R. (2019). BLUESHIFT: Rebalancing engineering engagement, integrity, and learning outcomes across an electronically-enabled remediation hierarchy. *The ASEE Computers in Education (CoED) Journal*, *10*(1).

DeMara, R. F., Turgut, D., Nassiff, E., Bacanli, S., & Bidoki, Neda H. (2018, June). Automated formation of peer learning cohorts using computer-based assessment data: A double-blind study within a Software Engineering course. In *Proceedings of American Association for Engineering Education Annual Conference*. Salt Lake City, UT.

Derry, H. (2019). *The 3 things to know about Tandem*. University of Michigan Academic Innovation. Retrieved from https://ai.umich.edu/blog/the-3-things-to-know-about-tandem.

Devaraj, S., Alfred, M., Madathil, K. C., & Gramopadhye, A. K. (2015, August). An Investigation of the Factors that Predict an Internet User's Perception of Anonymity on the Web. In *International Conference on Human Aspects of Information Security, Privacy, and Trust* (pp. 311-322). Springer, Cham.

Dillenbourg, P. (1999). *Collaborative learning: Cognitive and computational approaches. Advances in learning and instruction series*. New York, NY: Elsevier Science.

Dillenbourg, P., Baker, M. J., Blaye, A., & O'Malley, C. (1995). The evolution of research on collaborative learning. In E. Spada & P. Reiman (Eds.). *Learning in Humans and Machine: Towards an Interdisciplinary Learning Science,* (pp. 189–211). Oxford, UK: Pergamon.

Dillenbourg, P., Matuk, C., & Tissenbaum, M. (2016). Real-time visualization of student activities to support classroom orchestration. In *ICLS16: Proceedings of the12th International Conference of the Learning Sciences* (Vol. 2, pp. 1120-1127).

Dowell, N., Lin, Y., Godfrey, A., & Brooks, C. (2019, June). Promoting inclusivity through time-dynamic discourse analysis in digitally-mediated collaborative learning. *The 20th International Conference on Artificial Intelligence in Education*. Chicago, IL.

Dowell, N. M., Nixon, T. M., & Graesser, A. C. (2018). Group communication analysis: A computational linguistics approach for detecting sociocognitive roles in multiparty interactions. *Behavior research methods*, 1-35. doi:10.3758/s13428-018-1102-z

Dowell, N., Poquet, O., & Brooks, C. (2018). Applying group communication analysis to educational discourse interactions at scale. In Kay, J. & Luckin, R. (Eds.) *Rethinking Learning in the Digital Age: Making the learning Sciences Count, 13th International Conference of the Learning Sciences, 3.* London, UK: International Society of the Learning Sciences.

Dubrow, S., Dobbins, C., Bannan, B., Zaccaro, S., Peixoto, N., Purohit, H., Rana, M., & Au, M. (2017). Using IoT sensors to enhance simulation and training in multiteam systems. *The Interserve/Industry Training, Simulation and Education Conference* (I/ITSEC) Published Proceedings, 1-10.

Duffy, T. M., & Cunningham, D. J. (1996). Constructivism: Implications for the design and delivery of instruction. D. H. Jonassen (Ed.), *Handbook of Research for Educational Communications and Technology* (p. 170–198). New York, NY: Simon and Schuster.

E

Earnest, J. (2005, October). ABET engineering technology criteria and competency based engineering education. In *Proceedings Frontiers in Education 35th Annual Conference.* Indianapolis, IN. (pp. F2D-7). IEEE.

Edson, A, Bieda, K., Dorsey, C., Kimball, N., & Phillips, E. (2019), Math understanding in a digital collaborative environment. *2019 STEM for All Video Showcase: Innovations in STEM Education*. Retrieved from: https://stemforall2019.videohall.com/ presentations/1552.

Edyburn, D. L. (2010). Would you recognize universal design for learning if you saw it? Ten propositions for new directions for the second decade of UDL. *Learning Disability Quarterly*, *33*(1), 33–41. doi:10.1177/073194871003300103

Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction*, *20*(4), 399-483.

Erisman, W., & Steele, P. (2012). *From contact to completion: Supporting returning adult students in obtaining a college credential*. Washington, DC: *Higher Ed Insight.*

Ertmer, P. A., Glazewski, K. D., Jones, D., Ottenbreit-Leftwich, A., Goktas, Y., Collins, K., & Kocaman, A. (2009). Facilitating technology-enhanced problem-based learning (PBL) in the middle school classroom: An examination of how and why teachers adapt. *Journal of Interactive Learning Research*, *20*(1), 35-54.

F

Fathian, M., Saei-Shahi, M., & Makui, A. (2017). A new optimization model for reliable team formation problem considering experts' collaboration network. *IEEE Transactions on Engineering Management, 64*, 586-593. doi:10.1109/TEM.2017.2715825.

Feichtner, S. B., & Davis, E. A. (1984). Why some groups fail: A survey of students' experiences with learning groups. *Organizational Behavior Teaching Review*, *9*(4), 58-73.

Feng, M., Heffernan, N. T., & Koedinger, K. R. (2006, May). Addressing the testing challenge with a web-based e-assessment system that tutors as it assesses. *Proceedings of the 15th international conference on World Wide Web* (pp. 307-316). Edinburgh, Scotland, UK: ACM.

Fink, L. D. (2013). *Creating significant learning experiences: An integrated approach to designing college courses*. Hoboken, NJ: John Wiley & Sons.

Fiore, S. M., Graesser, A., & Greiff, S. (2018). Collaborative problem-solving education for the twenty-first-century workforce. *Nature Human Behaviour*, *2*(6), 367.

Fiore, S. M., Graesser, A., Greiff, S., Griffin, P., Gong, B., Kyllonen, ... von Davier, A. (2017). Collaborative problem solving: Considerations for the national assessment of educational progress. *National Center for Education Statistics.* ACTNext.

Fiore, S. M., Salas, E., Cuevas, H. M., & Bowers, C. A. (2003). Distributed coordination space: toward a theory of distributed team process and performance. *Theoretical Issues in Ergonomics Science*, *4*(3-4), 340-364.

Fischer, F., Kollar, I., Stegmann, K., & Wecker, C. (2013). Toward a script theory of guidance in computer-supported collaborative learning. *Educational Psychologist, 48*(1), 56–66. doi:10.1080/00461520.2012.748005

Fishman, B., & Dede, C. (2016). Teaching and technology: New tools for new times. In D. Gitomer & C. Bell (Eds.), *Handbook of Research on Teaching (5th ed.)*, pp. 1269-1334. New York, NY: Springer.

Francis, E. (2016). What exactly is depth of knowledge? Retrieved from http://edge.ascd.org/blogpost/what-exactly-is-depth-of-knowledge-hint-its-not-a-wheel

Fredricks, J. A. (2014). *Eight myths of student disengagement: Creating classrooms of deep learning*. Los Angeles, CA: Corwin Press.

Froyd, J. E., Borrego, M., Cutler, S., Henderson, C., & Prince, M. J. (2013). Estimates of use of research-based instructional strategies in core electrical or computer engineering courses. *IEEE Transactions on Education*, *56*(4), 393-399.

Fussell, S. R., & Setlock, L. D. (2014). Computer-mediated communication. Holtgraves, T. M. (Ed.), *The Oxford Handbook of Language and Social Psychology* (pp. 471-490). Oxford, UK: Oxford University Press. doi:10.1093/oxfordhb/9780199838639.013.020

G

Gallos, M. R., van den Berg, E., & Treagust, D. F. (2005). The effect of integrated course and faculty development: Experiences of a university chemistry department in the Philippines. *International Journal of Science Education*, *27*(8), 985–1006. doi:10.1080/09500690500038447

Galloway, S. M. (2016). Motivation or engagement? What's the difference? Retrieved from https://proactsafety.com/articles/motivation-or-engagement-whats-the-difference

Gay G. (2013). Teaching to and through cultural diversity. *Curriculum Inquiry, 43*, 48–70. doi:10.1111/curi.12002

Gillett-Swan, J. (2017). The challenges of online learning: Supporting and engaging the isolated learner. *Journal of Learning Design, 10*(1), 20-30. doi:10.5204/jld.v9i3.293

Gersick, C. J. (1991). Revolutionary change theories: A multilevel exploration of the punctuated equilibrium paradigm. *Academy of Management Review*, *16*(1), 10-36.

Goggins, S. P., Jahnke, I., & Wulf, V. (2013). *Computer-supported collaborative learning at the workplace.* New York, NY: Springer.

Goldstone, R. L., & Lupyan, G. (2016). Discovering psychological principles by mining naturally occurring data sets. *Topics in cognitive science, 8*(3), 548-568. doi:10.1111/tops.12212

Graham, S., & Weiner, B. (1996). Theories and principles of motivation. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 63-84). New York, NY: Macmillan Library Reference USA; London, England: Prentice Hall International.

Groom, V., Bailenson, J. N., & Nass, C. (2009). The influence of racial embodiment on racial bias in immersive virtual environments. *Social Influence*, *4*(3), 231-248.

Gweon, G., Jain, M., McDonough, J., Raj, B., & Rosé, C. P. (2013). Measuring prevalence of other-oriented transactive contributions using an automated measure of speech style accommodation. *International Journal of Computer-Supported Collaborative Learning, 8*(2), 245-265. doi:10.1007/s11412-013-9172-5

H

Hall, T. E., Meyer, A., & Rose, D. H. (2012). *Universal design for learning in the classroom: Practical applications*. New York, NY: The Guilford Press.

Hamari, J., Shernoff, D. J., Rowe, E., Coller, B., Asbell-Clarke, J., & Edwards, T. (2016). Challenging games help students learn: An empirical study on engagement, flow and immersion in game-based learning. *Computers in Human Behavior*, *54*, 170-179, dx.doi.org/10.1016/j.chb.2015.07.045

Herman, J.L., Davina C. &. Klein. D (1996). Evaluating equity in alternative assessment: An illustration of opportunity-to-learn issues. *The Journal of Educational Research, 89*(4), 246.

Herrenkohl, L. R., Palincsar, A. S., DeWater, L. S., & Kawasaki, K. (1999). Developing scientific communities in classrooms: A sociocognitive approach. *Journal of the Learning Sciences*, *8*(3-4), 451-493.

Herzberg, F. (1966). *Work and the nature of man*. Cleveland, OH: World Publishing

Hmelo-Silver, C., Jeong, H., Faulkner, R., & Hartley, K. (2017, January). Computer-supported collaborative learning in STEM domains: Towards a meta-synthesis. *Proceedings of the 50th Hawaii International Conference on System Sciences*, 2066-2075.

Holland, J. M., Major, D. A., & Orvis, K. A. (2012). Understanding how peer mentoring and capitalization link STEM students to their majors. *The Career Development Quarterly*, *60*(4), 343–354.

Hollingshead, A. (2018). Designing engaging online environments: Universal design for learning principles. Milheim, K. (Ed.), *Cultivating diverse online classrooms through effective instructional design*, (pp. 280-298). Hershey, PA: IGI Global. doi:10.4018/978-1-5225-3120-3.ch014

Hollingshead, A., & Carr-Chellman, D. (2019). Engaging learners in online environments utilizing universal design for learning principles. *eLearn*, *2019*(2), 3.

Holmegaard, H. T., Madsen, L. M., & Ulriksen, L. (2014). To choose or not to choose science: Constructions of desirable identities among young people considering a STEM higher education programme. *International Journal of Science Education*, *36*(2), 186–215.

Houston, N., (2011). The upgraded group rumbler. Retrieved from: https://www.chronicle.com/blogs/profhacker/the-upgraded-group-rumbler/35496

Howland, J. L., Jonassen, D. H., & Marra, R. M. (2013). *Meaningful learning with technology: Pearson New International Edition*. Pearson Higher Ed.

Huang, L., Bodnar, S., Zheng, J., Kazemitabar, M., Lajoie, S., Chen, Y., ... Wiseman, J. (2017, October). Visualizing dominant behaviours in problem-based learning environments: A case study analysis of the HOWARD platform. *E-Learn: World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education* (pp. 359-364). San Diego, CA: Association for the Advancement of Computing in Education (AACE).

I

Ismail, N. (2013, July). Use of an online peer feedback tool for student team projects. *EDULEARN13 Proceedings* (pp. 6345). Barcelona, Spain: IATED.

Ismaili, J., Ibrahimi, E. H. O. (2016). Mobile learning as alternative to assistive technology devices for special needs students. *Education and Information Technologies, 22*(3), 883-899. doi:10.007/s10639-015-9462-9

IMS. (2019). Agile Open Architecture & Extensive Ecosystem. Retrieved from: https://www.imsglobal.org/agileopenarchitectureextensiveecosystem.html

J

James, N. P. (2014). Golden rules for engaging students in learning activities. Retrieved from: https://www.edutopia.org/blog/golden-rules-for-engaging-students-nicolas-pino-james

Järvelä, S., & Hadwin, A. F. (2013). New frontiers: Regulating learning in CSCL. *Educational Psychologist*, *48*(1), 25-39.

Jasperson, J. S., Carter, P. E., & Zmud, R. W. (2005). A comprehensive conceptualization of post-adoptive behaviors associated with information technology enabled work systems. *MIS quarterly*, *29*(3), 525-557.

Johnson, D. W., Johnson, R. T., & Smith, K. A. (1998). *Active learning: Cooperation in the college classroom*. Edina, MN: Interaction Book Company.

Jonassen, D. H. (1995). Supporting communities of learners with technology: A vision for integrating technology with learning in schools. *Educational Technology*, *35*(4), 60-63.

K

Kaminsky, P., & Simchi-Levi, D. (1998). A new computerized beer game: A tool for teaching the value of integrated supply chain management. *Global supply chain and technology management*, *1*(1), 216-225.

Kane, B., Fetter, B., & Pestaluky, A. (2015). Keep talking and nobody explodes. *Steel Crate Games*. Ottawa: Canada.

Kang, R., Brown, S., & Kiesler, S. (2013, April). Why do people seek anonymity on the Internet? Informing policy and design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* Paris, France: Association for Computing Machinery. doi:10.1145/2470654.2481368

Kazemitabar M. A., Bodnar, S., Hogaboam, P., Chen, Y., Sarmiento, J. P., Lajoie, S. P., … Chan, L. (2016) Creating instructor dashboards to foster collaborative learning in on-line medical problem-based learning situations. Zaphiris P., Ioannou A. (Eds.). *Learning and Collaboration Technologies: Lecture Notes in Computer Science, 9753*. New York, NY: Springer.

Khaddage, F., Christensen, R., Lai, W., Knezek, G., Norris, C., & Soloway, E. (2015). A model driven framework to address challenges in a mobile learning environment. *Education and Information Technologies*, *20*(4), 625-640.

Killpack, T. L., & Melón, L. C. (2017). Toward inclusive STEM classrooms: What personal role do faculty play? *Life Sciences Education, 15*(3), 1-9. doi:10.1187/cbe.16-01-0020

Kirschner, P. A. (2002). Cognitive load theory: Implications of cognitive load theory on the design of learning. *Learning and Instruction, 12*(1), 1-10. doi:10.1016/S0959-4752(01)00014-7

Kizilcec, R. F., Piech, C., & Schneider, E. (2013). Deconstructing disengagement: analyzing learner subpopulations in massive open online courses. In *Proceedings of the Third International Conference on Learning Analytics and Knowledge - LAK '13*, 170. doi:10.1145/2460296.2460330

Koh, E., & Lim, J. (2012). Too early, too bad: uncovering and understanding the initial participation paradox in technology-mediated learning teams. *IEEE Transactions on Professional Communication*, *55*(1), 55-84.

Kuh, G. D., Pace, C. R., & Vesper, N. (1997). The development of process indicators to estimate student gains associated with good practices in undergraduate education. *Research in Higher Education*, *38*(4), 435–454.

Kulkarni, C., Cambre, J., Kotturi, Y., Bernstein, M. S., & Klemmer, S. R. (2015, March). Talkabout: Making distance matter with small groups in massive classes. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing* (pp.1116-1128).Vancouver, BC, Canada: Association for Computing Machinery.

Koch, K. (2017). Stay in the box! Embedded assistive technology improves access for students with disabilities. *Education Science, 7*(4), 1-8. doi:10.3390/educsci8020061

Koles, P. G., Stolfi, A., Borges, N. J., Nelson, S., & Parmelee, D. X. (2010). The impact of team-based learning on medical students' academic performance. *Academic Medicine*, *85*(11), 1739–1745. doi:10.1097/ACM.0b013e3181f52bed

L

Lace-Costigan, G. (2017). Perceptions of play: Using Play-Doh to enhance the student experience in Bioscience higher education. *International Journal of Game-Based Learning*, *7*(3), 26-37.

Ladson-Billings, G. (1995a). Toward a theory of culturally relevant pedagogy. *American Educational Research Journal, 32*, 465–491. doi:10.3102/00028312032003465

Ladson-Billings, G. (1995b). But that's just good teaching! The case for culturally relevant pedagogy. *Theory into Practice. 34*(3), 159-165. doi:10.1080/00405849509543675

Laurillard, D. (2009). The pedagogical challenges to collaborative technologies. *International Journal of Computer-Supported Collaborative Learning*, *4*(1), 5–20. doi:10.1007/s11412-008-9056-2

Lee, C. D. (1998). Culturally responsive pedagogy and performance-based assessment. *Journal of Negro Education, 67*, 268–279. doi:10.2307/2668195

Leonard, J., Burrows, A., & Kitchen, R. (2019). *Recruiting, preparing, and retaining STEM teachers for a global generation*. Netherlands: Brill.

Lersilp, T., & Lersilp, S. (2019). Use of information technology for communication and learning in secondary school students with a hearing disability. *Education Science, 9*(1), 1-14. doi:10.3390/educsci9010057

Lewin, K. (1946). Action research and minority problems. *Journal of Social Issues, 2*(4), 34-46.doi:10.1111/j.1540-4560.1946.tb02295.

Lin, J. W., & Lai, Y. C. (2013). Harnessing collaborative annotations on online formative assessments. *Journal of Educational Technology & Society*, *16*(1), 263-274.

Lin, Y., Dowell, N., Godfrey, A., & Brooks, C. (2019, June). Promoting inclusivity through time-dynamic discourse analysis in digitally-mediated collaborative learning. In *The 20th International Conference on Artificial Intelligence in Education (AIED 2019)*. Chicago, IL.

Lin, Y., Dowell, N., Godfrey, A., Choi, H., & Brooks, C. (2019, March). Modeling gender dynamics in intra and interpersonal interactions during online collaborative learning. In *Proceedings of the 9th International Conference on Learning Analytics & Knowledge* (pp. 431-435). Tempe, AZ: ACM.

Loughry, M. L., Ohland, M. W., & Woehr, D. J. (2014). Assessing teamwork skills for assurance of learning using CATME team tools. *Journal of Marketing Education*, *36*(1), 5-19.

Ludvigsen, S., Law, N., Rose, C. P., & Stahl, G. (2017). Frameworks for mass collaboration, adaptable scripts, complex systems theory, and collaborative writing. *International Journal of Computer-Supported Collaborative Learning*, *12*(2), 127-131.

Lynn Jr., L. E. (1999). *Teaching and Learning with Cases: A Guidebook*. Washington, DC: CQ Press.

M

MacLeod, J., Yang, H. H., & Xiang, Z. (2017). Understanding college students' intrinsic motivation and social interdependence in intercultural computer-supported collaborative learning between USA and China. *The Asia-Pacific Education Researcher, 26*(3-4), 205-217.doi:10.1007/s40299-017-0341-6

Maki, P & Kuh, GD. (2017). *Real-time student assessment: Meeting the imperative for improved time to degree, closing the opportunity gap, and assuring student competencies for 21st century needs.* Sterling, VA: Stylus.

Mallavarapu, A., Lyons, L., Uzzo, S., Wren, T., Levy-Cohen, R., & Slattery, B. (2019, May). Connect-to-Connected worlds: Piloting a mobile, data-driven reflection tool for an open-ended exhibit. In *CHI Conference on Human Factors in Computing Systems Proceedings (CHI 2019)*. Glasgow, Scotland, UK: ACM.

Martyn, M. (2007). Clickers in the classroom: An active learning approach. *Educause Quarterly*, *30*(2), 71.

Mathieu, J. E., Tannenbaum, S. I., Kukenberger, M. R., Donsbach, J. S., & Alliger, G. M. (2015). Team role experience and orientation: A measure and tests of construct validity. *Group & Organization Management*, *40*(1), 6-34.

Mayer, R. E. (2009). Constructivism as a theory of learning versus constructivism as a prescription for instruction. In S. Tobias & T. M. Duffy (Eds.), *Constructivist instruction: Success or failure?* (pp. 184-200). New York, NY: Routledge/Taylor & Francis.

Maznevski, M. L., & Chudoba, K. M. (2000). Bridging space over time: Global virtual team dynamics and effectiveness. *Organization Science*, *11*(5), 473-492.

Mazur, E., & Hilborn, R. C. (1997). *Peer instruction: A user's manual* (Vol. 5). Upper Saddle River, NJ: Prentice Hall.

Mejia, J. A. (2018). Critical theoretical frameworks in engineering education: An anti-deficit and liberative approach. *Education Science. 8*(4), 158. doi:10.3390/educsci8040158.

Meltzer, D. E., & Thornton, R. K. (2012). Resource letter ALIP–1: active-learning instruction in physics. *American Journal of Physics*, *80*(6), 478-496.

Michael J., (2006). Where's the evidence that active learning works? *Advances in Physiology Education*, *30*(4), 159–167.

Michaelsen, L. K., Knight, A. B., & Fink, L. D. (Eds.). (2002). *Team-based learning: A transformative use of small groups*. Westport, CT: Greenwood Publishing.

Michaelsen, L. K., & Schultheiss, E. E. (1989). Making feedback helpful. *Organizational Behavior Teaching Review*, *13*(1), 109-113.

Michaelsen, L. K., & Sweet, M. (2008). The essential elements of team-based learning. *New Directions for Teaching and Learning*, *2008*(116), 7–27. doi:10.1002/tl.330

Michaelsen, L. K., & Sweet, M. (2011). Team-based learning. *New Directions for Teaching and Learning*, *2011*(128), 41–51. doi:10.1002/tl.467

Miller, K., Lukoff, B., King, G., & Mazur, E. (2018). Use of a social annotation platform for pre-class reading assignments in a flipped introductory physics class. *Frontiers in Education, 3*(8), 1-12. doi:10.3389/feduc.2018.00008

Millheim, K. L. (2015). Cultural inclusivity in online learning. In Wright, R. D. (Ed.), *Student-teacher interaction in online learning environments* (pp. 76-88). Hershey, PA: IGI Global. doi:10.4018/978-1-4666-6461-6.ch004

Molenaar, I., & Chiu, M. M. (2014). Dissecting sequences of regulation and cognition: statistical discourse analysis of primary school children's collaborative learning. *Metacognition and Learning, 9*(2), 137-160.

Moriña, A. (2017). Inclusive education in higher education: Challenges and opportunities. *European Journal of Special Needs Education, 32*(1), 3-17. doi:10.1080/08856257.2016.1254964

Murphy, R.F. (2019). Artificial intelligence applications to support K-12 teachers and teaching: A review of promising applications, opportunities, and challenges. Retrieved from https://www.rand.org/pubs/perspectives/PE315.html

Mutch-Jones, K., Gasca, S., Pallant, A., & Lee, H. S. (2018). Teaching with interactive computer-based simulation models: Instructional dilemmas and opportunities in the High-Adventure Science project. *School Science and Mathematics*, *118*(5), 190-200.

N

Nachman, B. R. & Brown, K. R. (2019). Omission and othering: Constructing autism on community college websites. *Community College Journal of Research and Practic*e, 1-13. doi:10.1080/10668926.2019.1565845

National Academies of Sciences, Engineering, and Medicine. (2017). *Supporting students' college success: The role of assessment of intrapersonal and interpersonal competencies*. Washington, DC: National Academies Press. doi:10.17226/24697

National Center for Education Statistics. (2015). Demographic and enrollment characteristics of nontraditional undergraduates: 2011–12. Retrieved from https://nces.ed.gov/pubs2015/2015025.pdf

National Science Foundation. (2016). Harnessing the data revolution. Retrieved from https://www.nsf.gov/cise/harnessingdata/sciencedrivers/index.jsp

National Science Foundation, National Center for Science and Engineering Statistics. (2019). Women, minorities, and persons with disabilities in science and engineering. Retrieved from https://ncses.nsf.gov/pubs/nsf19304/

Nativi, S., Bigagli, L., Mazzetti, P., Boldrini, E., & Papeschi, F. (2009, February). GI-cat: a mediation solution for building a clearinghouse catalog service. In *2009 International Conference on Advanced Geographic Information Systems & Web Services* (pp. 68-74). Cancun, Mexico: IEEE.

Nebert, D. (2000). Building a geospatial data clearinghouse for data discovery and access. *Statistical Journal of the United Nations Economic Commission for Europe*, *17*(2), 149-156.

Nieto, S. (2010). *Language, culture, and teaching: Critical perspectives* (2nd ed.). New York, NY: Taylor & Francis.

Nilizadeh, S., Groggel, A., Lista, P., Das, S., Ahn, Y. Y., Kapadia, A., & Rojas, F. (2016, March). Twitter's Glass Ceiling: The effect of perceived gender on online visibility. In *Tenth International AAAI Conference on Web and Social Media* (pp. 289-298). Cologne, Germany: AAAI.

O

Obizoba, C. (2016). Effective facilitation methods for online teaching. *International Journal of Higher Education Management, 2(2)*, 14-25.

O'Donnell, A. M., & O'Kelly, J. (1994). Learning from peers: Beyond the rhetoric of positive results. *Educational Psychology Review*, *6*(4), 321-349.

O'Dwyer, B. (2017, March*). Technology-based learning for team-based learning – opportunities, benefits and considerations for technology supported TBL.* Poster presented at the annual meeting of the Team-Based Learning Collaborative, Orlando, FL.

O'Dwyer, B. (2018, March). *Enhanced technology for team-based learning ("TBL"): Impact of enhanced TBL software.* Poster presented at the annual meeting of the Team-Based Learning Collaborative, San Diego, CA.

O'Dwyer, B. (2018, September). *Training the next generation in aviation with technology enabled team-based learning.* Oral presentation at the AviAsian Conference at the Singapore Aviation Academy, Singapore.

Osatuyi, B., Osatuyi, T., & De La Rosa, R. (2018). Systematic review of gamification research in IS education: A multi-method approach. *Communications of the Association for Information Systems*, *42*(1), 95-124. doi:10.17705/1CAIS.04205

P

Paas, F., Tuovinen, J. E., Tabbers, H., & Van Gerven, P. W. M. (2003). Cognitive load measurement as a means to advance cognitive load theory. *Educational Psychologist*, *38*(1), 63-71.

Pajares, F. (2003). Self-efficacy beliefs, motivation, and achievement in writing: A review of the literature. *Reading & Writing Quarterly, 19*(2), 139-158. doi:10.1080/10573560308222

PaleBlue XYZ. (2018). Retrieved from: https://www.paleblue.xyz

Palmer, T. A., Burke, P. F., & Aubusson, P. (2017). Why school students choose and reject science: A study of the factors that students consider when selecting subjects. *International Journal of Science Education*, *39*(6), 645-662.

Palomares, N. A., & Lee, E. J. (2010). Virtual gender identity: The linguistic assimilation to gendered avatars in computer-mediated communication. *Journal of Language and Social Psychology*, *29*(1), 5-23.

Pan, Z., Cheok, A. D., Yang, H., Zhu, J., & Shi, J. (2006). Virtual reality and mixed reality for virtual learning environments. *Computers & Graphics*, *30*(1), 20-28.

Panitz, T. (1999). Collaborative versus cooperative Learning: A comparison of the two concepts which will help us understand the underlying nature of interactive learning. Retrieved from https://eric.ed.gov/?id=ED448443

Parmelee, D., Michaelsen, L. K., Cook, S., & Hudes, P. D. (2012). Team-based learning: A practical guide: AMEE Guide No. 65. *Medical Teacher*, *34*(5), e275–e287. doi:10.3109/0142159X.2012.651179

Parson, L. (2016). Are STEM syllabi gendered? A feminist critical discourse analysis. *The Qualitative Report*, *21*(1), 102-116.

Passel, J. S., Cohn, D. V., & Lopez, M. H. (2011). Hispanics account for more than half of nation's growth in past decade. Retrieved from https://www.pewhispanic.org/2011/03/24/hispanics-account-for-more-than-half-of-nations-growth-in-past-decade/

Paulin, D. & Haythornthwaite, C. (2016). Crowdsourcing the curriculum: Redefining e-learning practices through peer-generated approaches. *The Information Society,* 32(2), 130–142.

Paxton, A., & Griffiths, T. L. (2017). Finding the traces of behavioral and cognitive processes in big data and naturally occurring datasets. *Behavior Research Methods, 49*(5), 1630-1638. doi:10.3758/s13428-017-0874-x

Penuel, W. R., & Van Horne, K. (2016). Prompts for integrating crosscutting concepts into assessment and instruction. Retrieved from http://stemteachingtools.org/brief/41

Piaget, J. (1953). *The origin of intelligence in the child*. New York, NY: Routledge and Kegan Paul.

Popov, V., Biemans, H. J. A., Brinkman, D., Kuznetsov, A., & Mulder, M. (2013). Facilitation of computer-supported collaborative learning in mixed- versus same-culture dyads: Does a collaboration script help? *The Internet and Higher Education, 19*, 36-48.

Popov, V., Brinkman, D., Biemans, H. J. A., Mulder, M., Kuznetsov, A., & Noroozi, O. (2012). Multicultural student group work in higher education: An explorative case study on challenges as perceived by students. *International Journal of Intercultural Relations, 36*(2), 302-317

Popov, V., Noroozi, O., Barrett, J. B., Biemans, H. J. A., Teasley, S. D., Slof, B., & Mulder, M. (2014). Perceptions and experiences of, and outcomes for, university students in culturally diversified dyads in a computer-supported collaborative learning environment. *Computers in Human Behavior, 32*(C), 186-200. doi:10.1016/j.chb.2013.12.008

President's Council of Advisors on Science and Technology (PCAST). (2010). Prepare and inspire: K–12 education in science, technology, engineering, and math (STEM) for America's future. PCAST. Retrieved from https://eric.ed.gov/?id=EJ913287

President's Council of Advisors on Science and Technology (PCAST). (2012). Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. PCAST. Retrieved from https://eric.ed.gov/?id=ED541511

Prieto, E., & Dugar, N. (2017). An enquiry into the influence of mathematics on students' choice of STEM careers. *International Journal of Science and Mathematics Education*, *15*(8), 1501-1520.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, *93*(3), 223–231.

Q

Quintana, C., Reiser, B., Davis, E., Krajcik, J., Fretz, E., Duncan, R., ... Soloway, E. (2004). A scaffolding design framework for software to support science inquiry. *The Journal of the Learning Sciences, 13*(3), 337-386.

R

Raker, J. R., & Holme, T. A. (2014). Investigating faculty familiarity with assessment terminology by applying cluster analysis to interpret survey data. *Journal of Chemical Education*, *91*, 1145–1151.

Ramenzoni, V. C., Davis, T. J., Riley, M. A., Shockley, K., & Baker, A. A. (2011). Joint action in a cooperative precision task: nested processes of intrapersonal and interpersonal coordination. *Experimental Brain Research, 211(3-4)*, 447-457. doi:10.1007/s00221-011-2653-8

Reidsma, D., Heylen, D. K. J., & Ordelman, R. J. F. (2006). Annotating emotions in meetings. *Proc. of the fifth international conference on Language Resources and Evaluation, LREC 2006* (pp. 1117-1122). Paris, France: ELRA.

Reilly, J. M., & Dede, C. (2019, March). Differences in student trajectories via filtered time series analysis in an immersive virtual world. In *Proceedings of the 9th International Conference on Learning Analytics & Knowledge* (pp. 130-134). ACM.

Richardson, M. J., Marsh, K. L., & Schmidt, R. C. (2005). Effects of visual and verbal interaction on unintentional interpersonal coordination. *Journal of Experimental Psychology: Human Perception and Performance, 31*(1).

Riegle-Crumb, C., King, B., & Irizarry, Y. (2019). Does STEM stand out? Examining racial/ethnic gaps in persistence across postsecondary fields. *Educational Researcher, 48*(3), 133-144.doi:10.3102/0013189X19831006

Rogers, E. M. (2010). *Diffusion of Innovations* (5th ed.). New York, NY: Simon and Schuster.

Rolfe, V. (2015). A systematic review of the socio-ethical aspects of massive online open courses. *European Journal of Open, Distance and e-Learning, 18*(1), 52-71. doi:10.1515/eurodl-2015-0004.

Rose, D. H., & Meyer, A. (2006). *A practical readers in Universal design for learning*. Cambridge, MA: Harvard Education Press.doi:10.1177/0162643418759340

Ruvalcaba, O., Werner, L., & Denner, J. (2016, February). Observations of pair programming: variations in collaboration across demographic groups. In *Proceedings of the 47th ACM Technical Symposium on Computing Science Education* (pp. 90-95). Memphis, TN: ACM.

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist, 55*(1), 68-78.

S

Salas, E., Stevens, R., Gorman, J., Cooke, N. J., Guastello, S., & von Davier, A. (2015, September). What will quantitative measures of teamwork look like in 10 years? In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 59*(1), 235-239. SAGE Publications.

Saleh, A., Silver, C. H., Chen, Y., Shanahan, K., Rowe, J., & Lester, J. (2018a). Scaffolding peer facilitation in computer-supported problem-based learning environments. In Kay, J. and Luckin, R. (Eds.) *Rethinking learning in the digital age: Making the learning sciences count, 13th International Conference of the Learning Sciences (ICLS) 2018, Volume 3*. London, UK: International Society of the Learning Sciences. doi:10.22318/cscl2018.1831

Saleh, A., Shanahan, K., Georgen, C., Hmelo-Silver, C., Rowe, J. P., & Lester, J. C. (2018b). Scaffolding middle schoolers' construction of scientific models. *Paper presented at the American Educational Research Association, New York, NY.*

Saleh, A., Hmelo-Silver, C., Chen, Y., Shanahan, K., Rowe, J., & Lester, J. (2018c, July). Scaffolding peer facilitation in computer-supported problem-based learning environments. In Kay, J. and Luckin, R. (Eds.) *Rethinking learning in the digital age: Making the learning sciences count, 13th International Conference of the Learning Sciences (ICLS) 2018, Volume 3*. London, UK: International Society of the Learning Sciences. doi:10.22318/cscl2018.1831

Sanders, M., Spiegel, S., & Sherer, J. Z. (2018). Moving beyond “does active learning work?” with *the Engineering Learning Observation Protocol (ELCOT)*. Paper presented at the 2018 American Society for Engineering Education (ASEE) annual conference: Salt Lake City, UT.

Savaria, M., & Monteiro, K. (2017). A critical discourse analysis of engineering course syllabi and recommendations for increasing engagement among women in STEM. *Journal of STEM Education: Innovations & Research, 18*(1), 92-97.

Scardamalia, M. & Bereiter, C. (1996). Computer support for knowledge-building communities. In T. Koschmann (Ed.), *CSCL: Theory and practice of an emerging paradigm* (pp. 249-268). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Scardamalia, M., & Bereiter, C. (2006). Knowledge building: Theory, pedagogy, and technology. In K. Sawyer (Ed.), *Cambridge Handbook of the Learning Sciences* (pp. 97-118). New York, NY: Cambridge University Press.

Scholtes, P. R., Joiner, B. L., & Streibel, B. J. (2003). The Team Handbook. Methuen, MA: GOAL/QPC.

Schraw, G., & Robinson, D. H. (2008). Recent Innovations in Educational Technology that *Facilitate Student Learning*. Charlotte, NC: Information Age Publishing, Inc.

Schwortz, A. C., Burrows, A. C., & Guffey, S. K. (2017). Mentoring partnerships in science education. *Educational Action Research*, *25*(4), 630-649. doi:10.1080/09650792.2016.1221838

Shaffer, D. W. (2017). Quantitative ethnography. Madison, WI: Cathcart Press.

Shaffer, D., & Ruis, A. (2017). Epistemic network analysis: A worked example of theory-based learning analytics. In Lang, C., Siemens, G., Wise, A., & Gašević, D. (Eds.), *Handbook of learning analytics, 1st Edition*. Society for Learning Analytics Research.

Schreffler, J., Vasquez III, E., Chini, J., & James, W. (2019). Universal Design for Learning in postsecondary STEM education for students with disabilities: a systematic literature review. *International Journal of STEM Education, 6*(8), 1-10. doi:10.1186/s40594-019-0161-8

Siemens, G. (2013). Learning Analytics: The emergence of a discipline. American Behavioral *Scientist*, *57*(10), 1380–1400. https://doi.org/10.1177/0002764213498851

Sigrid, K. & St. Amant, K. (2008). Handbook of Research on Computer Mediated Communication. Hershey, PA: information Science Reference: IGI Global.

Simpson, S., Clemens, R., Killingsworth, D. R., & Ford, J. D. (2015). Creating a culture of communication: A graduate-level STEM communication fellows program at a science and engineering university. *Across the Disciplines*, *12*(3). Retrieved from https://wac.colostate.edu/atd/special/graduate/

Sinha, S., Rogat, T. K., Adams-Wiggins, K. R., & Hmelo-Silver, C. E. (2015). Collaborative group engagement in a computer-supported inquiry learning environment. *International Journal of Computer-Supported Collaborative Learning*, *10*(3), 273-307.

Siwatu, K. O. (2007). Preservice teachers’ culturally responsive teaching self-efficacy and outcome expectancy beliefs. *Teaching and Teacher Education, 23*(7), 1086-1101. doi:10.1016/j.tate.2006.07.011

Snyder, J. J., Sloane, J. D., Dunk, R. P., & Wiles, J. R. (2016). Peer-led team learning helps minority students succeed. PLoS Biology, 14(3), 1-7. doi:10.1371/journal.pbio.1002398

Sottilare, R. A., Burke, C. S., Salas, E., Sinatra, A. M., Johnston, J. H., & Gilbert, S. B. (2018). Designing adaptive instruction for teams: A meta-analysis. *International Journal of Artificial Intelligence in Education*, *28*(2), 225-264. doi:10.1007/s40593-017-0146-z

Sparrow, M. K. (2019). Group Rumbler ("GRumbler") Excel file. Retrieved from https://sites.hks.harvard.edu/fs/msparrow/GRumbler--updated%20files/GRumbler.xlsm

Spector, J. M. (2008). Expertise and dynamic tasks. In Qudrat-Ullah, H., Spector, J. M., & Davidsen, P. (Eds.), *Complex decision making: Theory and practice,* (pp. 25-37). New York, NY: Springer, NECSI.

Stahl, G., Koschmann, T., & Suthers, D. (2014). Computer-supported collaborative learning. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (2nd ed., pp. 479–500). New York, NY: Cambridge University Press. doi:10.1017/CBO9781139519526.029

Stains, M., Harshman, J., Barker, M. K., Chasteen, S. V., Cole, R., DeChenne-Peters, S. E., ... Young, A.M. (2018). Anatomy of STEM teaching in North American universities. *Science*, *359*(6383), 1468-1470. doi:10.1126/science.aap8892

Stevens, R, Galloway, T. (2017). Are neurodynamic organizations a fundamental property of teamwork? Frontiers in Psychology, 8, 1-16. doi:10.3389/fpsyg.2017.00644

Suchman, L. (1996). Supporting articulation work. In Kling, R. (Ed.), Computerization and *Controversy* (2nd ed., pp. 407–423). doi:10.1016/B978-0-12-415040-9.50118-4

T

Tatum, A. W. (2000). Breaking down barriers that disenfranchise African American adolescent readers in low-level tracks. *Journal of Adolescent & Adult Literacy, 44*(1), 52-64.

Theobald, E. J., Eddy, S. L., Grunspan, D. Z., Wiggins, B. L., & Crowe, A. J. (2017). Student perception of group dynamics predicts individual performance: Comfort and equity matter. *PLoS ONE, 12(*7), e0181336. doi:10.1371/journal.pone.0181336

Tennial, R. E., Solomon, E. D., Hammonds-Odie, L., McDowell, G. S., Moore, M., Roca, A. I., & Marcette, J. (2019). Formation of the inclusive environments and metrics in Biology education and research (iEMBER) network: Building a culture of diversity, equity, and inclusion. *Life Sciences Education, 18*(1), 1-8. doi:10.1187/cbe.18-03-0042

Topping, K. J. (2005). Trends in peer learning. Educational Psychology, 25(6), 631–645. https://doi.org/10.1080/01443410500345172

Tuckman, B. W. (1965). Developmental sequence in small groups. *Psychological Bulletin, 63*(6), 384-399. http://dx.doi.org/10.1037/h0022100

U

Uzuner, S. (2009). Questions of culture in distance learning: A research review. *The International Review of Research in Open and Distributed Learning, 10*(3). doi:10.19173/irrodl.v10i3.690

V

Valencia, R. (Ed.). (1997). *The evolution of deficit thinking in educational thought and practice*. New York, NY: Falmer.

Vennix, J., den Brok, P., & Taconis, R. (2017). Perceptions of STEM-based outreach learning activities in secondary education. Learning Environments Research, 20(1), 21-46.

Vygotsky, L.S. (1978). Mind in Society. Cambridge, MA: Harvard University Press.

W

Walker, S. E. (2003). Active learning strategies to promote critical thinking. *Journal of Athletic Training*, *38*(3), 263.

Wen, M. (2016). Investigating virtual teams in massive open online courses: Deliberation-based virtual team formation, discussion mining and support. *PhD Thesis*.

Wen, M., Maki, K., Dow, S., Herbsleb, J. D., & Rose, C. (2017). Supporting virtual team formation through community-wide deliberation. *Proceedings of the ACM on Human-Computer Interaction*, *1*(CSCW), 109.

Wertsch, J. V. (1998). *Mind as action.* New York, NY: Oxford University Press.

White, T., Brady, C., Huang, W., & Stevens, M. (2019). A distributed-by-design approach to supporting collaborative learning with dynamic mathematics software. *Educational Designer, 3*(12): *Journal of the International Society for Design and Development in Education.*

Wieman, C. E., Adams, W. K., Loeblein, P., & Perkins, K. K. (2010). Teaching physics using PhET simulations. *The Physics Teacher*, *48*(4), 225-227.

Wise, A. (2019a, April). Analytics, adaptivity & agency in Digitally-Mediated Team Learning. Keynote presentation at the *Digitally-Mediated Team Learning NSF Workshop*. Orlando, FL.

Wise, A. F. (2019b). Learning analytics: Using data-informed decision-making to improve teaching and learning. In O. O. Adesope & A. G. Rud (Eds.), *Contemporary Technologies in Education: Maximizing Student Engagement, Motivation, and Learning* (pp. 119–143). doi:10.1007/978-3-319-89680-9_7

Wise, A. F. & Schwarz, B. S. (2017). Visions of CSCL: Eight provocations for the future of the field. *International Journal of Computer-Supported Collaborative Learning*, *12*(4), 423-467.

Wolff, G. (2016). Quizlet Live: The classroom game now taking the world by storm. *The Language Teacher*, *40*(6), 25-27.

World Economic Forum. (2019). *Leading through the fourth industrial revolution: Putting people at the centre* [White paper]. Retrieved from http://www3.weforum.org/docs/WEF_Leading_through_the_Fourth_Industrial_Revolution.pdf

Z

Zaccaro, S. J., Fletcher, L. S., & Dechurch, L. (2017). Creativity and innovation in multiteam systems. *Team Creativity and Innovation*. Oxford, UK: Oxford University Press. doi:10.1093/oso/9780190222093.003.0009.

Zhang, J. (in press). Creativity as sustained social practices: Four pillars for creative learning design. Cambridge, MA: MIT Press.

Zhang, J., & Chen, M. H. (2019). Idea thread mapper: Designs for sustaining student-driven knowledge building across classrooms. Lyon, France: *International Conference of Computer-Supported Collaborative Learning (CSCL 2019)*.

Zhang, J., Tao, D., Chen, M. H., Sun, Y., Judson, D., & Naqvi, S. (2018). Co-organizing the collective journey of inquiry with idea thread mapper. *Journal of the Learning Sciences*, *27*(3), 390-430.

Zhou, W., Simpson, E., & Domizi, D. P. (2012). Google Docs in an out-of-class collaborative writing activity. *International Journal of Teaching and Learning in Higher Education*, *24*(3), 359-375.

Zuckerman, O., Blau, I., & Monroy-Hernández, A. (2009). Children's participation patterns in online communities. *Interdisciplinary Journal of E-Learning and Learning Objects, 5(1)*, 263-274.

Appendix A: Glossary of Acronyms and Terms

Digitally-Mediated Team Learning (DMTL)

Digitally-Mediated Team Learning (DMTL) encompasses cooperative learning in a digital classroom-based synchronous setting. The focus of DMTL can include STEM problem-solving and design activities within a classroom setting in real-time. Every team members' role is valued and members can adopt shifting roles during the activity. During a DMTL activity, the instructor supports rather than directs the learning experience via the shared virtual space. Work products and knowledge are co-constructed utilizing common resources and mutually-shared views of the exercise. DMTL leverages data analytics and the potential of machine learning to advance learning outcomes and scalability.

Term	Acronym	Definition with Citation
Activity Clones	**AC**	Activity clones are variations of the learning assignment which mitigate learner crosstalk and the availability of previous solutions to the same or similar learning activities. Activity clones are typically generated by modifying elements of the problem specification or permuting the quantities sought. A primary objective of Activity Cloning is for students to be afforded the opportunity to participate in comparable learning activities, while simultaneously reducing the propensity for them to share answers (DeMara, Sheikhfaal, Wilder, Chen, & Hartshorne, 2019, p. 8).
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)
Coded Language		Coded language may be a phrase or a sentence that targets a specific group with shared characteristics such as race, gender, ethnicity or sexual preference. These phrase are often nuanced with bias or prejudice. For example, coded language is often used "to bring up racist views without seeming racist" (Bush, 2004, p. xi).
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).
Computer-Supported Collaborative Work	**CSCW**	"... an identifiable research field focused on the role of the computer in group work" (Suchman, 1996, p. 9).
Cooperative Learning	**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).
Digitally-Mediated	**DM**	Some form of digital technology is involved in transacting communication or development of a digital product or process.
Educational Data Mining (K-12)	**EDM**	“Educational Data Mining is concerned with developing methods for exploring the unique types of data that come from educational settings, and using those methods to better understand students, and the settings which they learn in." (Baker & Yacef, 2009, p. 4).
Extended reality	**XR**	Extended Reality (XR) references Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR.
Flipped classroom	**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, 2019b, 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).
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)
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).
Project-based Learning	**PjBL**	“Project Based Learning is a teaching method in which students gain knowledge and skills by working for an extended period of time to investigate and respond to an authentic, engaging, and complex question, problem, or challenge” (Buck Institute for Education PBLworks, n.d.).
Psychophysiological assessment of cognitive processing	**PACP**	"techniques include measures of heart activity..., brain activity..., and eye activity. Psychophysiological techniques utilize the combination of physiological variables and learning process markers (such as task completion rate or percent of correct responses on transfer measures). Psychophysiological measures can best be used to visualize the detailed trend and pattern of cognitive load..." (Schraw & Robinson, 2008, p. 20) Facial reaction, eye tracking, and attention.
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 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).
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.
Universal design for learning	**UDL**	“The term universal design for learning means a scientifically valid framework for guiding educational practice that - (a) provides flexibility in the ways information is presented, in the ways students respond or demonstrate knowledge and skills, and in the ways students are engaged; and (b) reduces barriers in instruction, provides appropriate accommodations, supports, and challenges, and maintains high achievement expectations for all students, including students with disabilities

		and students who are limited English proficient" (Edyburn, 2010, p. 34).
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)

Appendix B. Workshop Flow and Agenda

The DMTL Workshop took place March 31 - April 2, 2019 in the Morgridge International Reading Center at the University of Central Florida. In the months leading up to the Workshop, qualified participants were selected based on an application which included an Expertise Profile listing their qualifications and a Position Abstract on a specific research direction relating to DMTL. After selection of participants was completed, track templates were made available for participants to note talking points ahead of the Workshop.

Over the duration of the Workshop, participants attended parallel breakout sessions (one for each track) where they used these same track templates to record ideas on the state-of-the-art, challenges and future research directions regarding each track. After the conclusion of the Workshop, an action committee was assembled, consisting of participants from each of the four tracks: action committee members served as editors for their respective track in completion of this White Paper. The overall Workshop flow is summarized below, followed by an hourly agenda of activities which took place during the Workshop.

DMTL Workshop Agenda	
Sunday, 31 March 2019 Attendees arrive and are introduced to each other through a poster session and social mixer.	
3:00 - 3:10	**Reception Welcome** *(Dr. Michael Georgiopoulos: Dean of College of Engineering & Computer Science - UCF)*

3:10 - 6:00	**Poster Session / Demos:** Researcher/Student Poster Session, Demos, and Industry Table
3:10 - 6:30	**Social Mixer:** Reception and Hors d'oeuvres - *McGraw Hill Education*
6:00 - 6:30	**Poster Awards**
7:00	**Dinner** - Restaurants for dinner at attendees' own expense / opportunity to coordinate with peers
Monday, 1 April 2019 Attendees participate in their first day of breakout sessions; highlights include keynote speakers, panel discussion, and tour of digital learning facilities.	
8:30 - 9:00	**Coffee & Pastry:** Networking/Conversation
9:00 - 9:05	**Welcome** *(Dr. Debra Reinhart: Associate Vice President for Research and Scholarship - UCF)*
9:00 - 10:00	**Keynote:** "Balancing Learning and Productivity Through Shared Cognition in Team-Based Learning" *(Dr. Carolyn Rose - CMU)*
10:00 - 11:00	**Workshop Overview** *(Drs. Ronald DeMara - UCF, Laurie O. Campbell - UCF, Richard Hartshorne - UCF)*
11:00 - 1:00	**Parallel Breakout Sessions for Tracks 1 to 4** *(Led by Track Co-Chairs)*
1:00 - 1:05	**Lunch Welcome** *(Dr. Pamela "Sissi" Carroll: Dean of College of Community Innovation and Education - UCF)*
1:05 - 2:00	**Lunch & Presentation:** "Analytics, Adaptivity, and Agency in Digitally-Mediated Team Learning" *(Dr. Alyssa Wise - NYU)*
2:00 - 5:00	**Parallel Breakout Sessions for Tracks 1 to 4** *(Led by Track Co-Chairs)*
5:00 - 5:45	**Panel Discussion:** "Future of Instructional Technologies for Cooperative Learning: 1, 3, and 5 Year Research" *(Drs. Sarah Carey - MHE, Cathleen A. Norris - UNT, Matthew Ohland - Purdue, Elliot Soloway - Michigan, and Jianwei Zhang - Albany)*
5:45 - 6:00	**Digital Learning: Today and Initiatives** *(Dr. Kelvin Thompson: Executive Director of Center for Distributed Learning - UCF)*

6:00 - 7:00	**Tours:** Active Learning Sandbox, EPC, and Mixed-Mode Production Facility (refer to *Section 4* below)
8:00	**Dinner** - Restaurants for dinner at attendees' own expense / opportunity to coordinate with peers
Tuesday, 2 April 2019 Attendees participate in a second day of breakout sessions focused on refining and organizing ideas in track templates; action committee is formed to edit White Paper.	
8:30 - 9:00	**Coffee & Pastry:** Networking/Conversation
9:00 - 9:05	**Welcome** *(Dr. Melody Bowdon: Interim Vice Provost of the Division of Teaching and Learning - UCF)*
9:05 - 10:00	**Keynote:** "Collaboration via Constructing Shared Mental Models: The Value of Immersive Experiences and Representations" *(Dr. Christopher Dede - Harvard)*
10:00 - 11:00	**Debrief** *(Dr. Ronald DeMara - UCF and Track Co-Chairs)*
11:00 - 1:00	**Parallel Breakout Sessions for Tracks 1 to 4** *(Led by Track Co-Chairs)*
1:00 - 1:05	**Lunch Welcome** *(Dr. Wendy Howard: Program Director of Pegasus Innovation Lab - UCF)*
1:05 - 2:00	**Lunch & Presentation:** "Shared Regulation in CSCL" *(Dr. Angela M. O'Donnell - Rutgers)*
2:00 - 3:30	**Parallel Breakout Sessions for Tracks 1 to 4** *(Led by Track Co-Chairs)*
3:30 - 4:30	**Action Committee Formation** *(Led by Track Co-Chairs)*
7:00	**Dinner -** *Restaurants for dinner at attendees' own expense / opportunity to coordinate with peers*

Appendix C: Workshop Participants

Participant	Institution	Track
Roger Azevedo	University of Central Florida	2
Brenda Bannan	George Mason University	2
Joseph Beck	Worcester Polytechnic Institute	2
Jennifer Blacklock	Colorado School of Mines	2
Leslie Bondaryk	Concord Consortium	1
Kristy Elizabeth Boyer	University of Florida	1
Laurie O. Campbell	University of Central Florida	4
Sarah Carey	McGraw Hill Education	3
John Carroll	Pennsylvania State University	3
Zhongzhou Chen	University of Central Florida	2
Min Chi	North Carolina State University	2
Leanne Coyne	University of Texas at Tyler	3
Melissa Dagley	University of Central Florida	4
Chris Dede	Harvard University	3
Ronald F. DeMara	University of Central Florida	1
Julie Donnelly	University of Central Florida	3
Chad Dorsey	Concord Consortium	1
Nia Dowell	University of Michigan	4
Danielle Espino	Pepperdine University	4
Steve Fiore	University of Central Florida	3
Benjamin Gallegos	University of Portland	4
Edward Gehringer	North Carolina State University	2
Glenda Gunter	University of Central Florida	4

Brian Harte	St. John's University	3
Richard Hartshorne	University of Central Florida	3
Caroline Haythornthwaite	Syracuse University	3
Eloy Hernandez	University of Central Florida	3
Wendy Howard	University of Central Florida	1
Zhewei Hu	North Carolina State University	2
Hwee-Joo Kam	University of Tampa	3
Fengfeng Ke	Florida State University	1
Seung Lee	Pepperdine University	2
Hongli Li	Georgia State University	2
Leilah Lyons	New York Hall of Science	1
Shanshan Ma	University of North Texas	2
Brian Magerko	Georgia Tech	2
Thayer Merritt	University of Texas at Tyler	1
Homero Murzi	Virginia Tech	2
Gloria Niles	University of Hawaii West Oahu	4
Cathie Norris	University of North Texas	1
Angela O'Donnell	Rutgers University	3
Brian O'Dwyer	Embry-Riddle U. & CognaLearn	1
Matthew Ohland	Purdue University	1
Babajide Osatuyi	The Pennsylvania State University	3
Katia Passerini	St. John's University	3
Amanda Perez	Carnegie Mellon University	2
Vitaliy Popov	University of San Diego	4
Hossein Pourmeidani	University of Central Florida	1
Debra Reinhart	University of Central Florida	4

Carolyn Rose	Carnegie Mellon University	1
Asmalina Saleh	Indiana University	3
Soheil Salehi	University of Central Florida	1
Shadi Sheikhfaal	University of Central Florida	1
George Siemens	University of Texas At Arlington	2
Elliot Soloway	University of Michigan	1
Michael Spector	University of North Texas	2
Sam Spiegel	Colorado School of Mines	2
Frank Starmer	Duke University	2
Ron Stevens	UCLA School of Medicine	2
Michael Stucker	Indiana University	2
Jody K. Takemoto	The University of Texas at Tyler	3
Adrian Tatulian	University of Central Florida	1
Michelle Taub	University of Central Florida	2
Tian Tian	University of Central Florida	1
Gina Tesoriero	University of Washington	3
Jennifer Tsan	North Carolina State University	2
Jessica Vandenberg	North Carolina State University	2
Kenneth Walsh	Oregon State University	3
Alyssa Wise	New York University	3
Sally Wu	University of Wisconsin, Madison	3
Dezhi Wu	University of South Carolina	2
Wanli Xing	Texas Tech University	2
Soobin Yim	University of California, Irvine	4
Jianwei Zhang	University at Albany	1

The following manuscript is publicly-available for downloading as a PDF at the link below:
https://www.asee.org/public/conferences/140/papers/26880/view

Methods and Outcomes of the NSF Project on Synthesizing Environments for Digitally-Mediated Team Learning

Ronald F. DeMara[1a], Joseph E. Beck[2], Laurie O. Campbell[1b], Richard Hartshorne[1b], Samuel Spiegel[3], Zhongzhou Chen[1c], Melissa Dagley[1d], Eloy Hernandez[1e], Tian Tian[1f], Julie Donnelly[1g], Adrian Tatulian[1a], Shadi Sheikhfaal[1a], Hossein Pourmeidani[1a], Hans Esteves[1b], and Tara Gibson[1b]

{[1a]Department of Electrical and Computer Engineering, [1b]Department of Learning Sciences and Educational Research, [1c]Department of Physics, [1d]Center for Initiatives in Science Technology, Engineering, and Mathematics, [1e]Department of Chemistry. [1f]Department of Mechanical and Aerospace Engineering, and [1g]Division of Digital Learning, University of Central Florida, Orlando, FL 32816}
{[2] Trefny Innovative Instruction Center, University of Colorado Mines, Golden, CO 80401}
{[3] Department of Computer Science, Worcester Polytechnic Institute, Worcester, MA 01609}

Abstract
This poster paper describes the authors' single-year National Science Foundation (NSF) project DRL-1825007 titled, "DCL: Synthesis and Design Workshop on Digitally-Mediated Team Learning" which has been conducted as one of nine awards within NSF-18-017: Principles for the Design of Digital STEM Learning Environments. Beginning in September 2018, the project conducted the activities herein to deliver a three-day workshop on *Digitally-Mediated Team Learning* (*DMTL*) to convene, invigorate, and task interdisciplinary science and engineering researchers, developers, and educators to coalesce the leading strategies for digital team learning. The deliverable of the workshop is a White Paper composed to identify one-year, three-year, and five-year research and practice roadmaps for highly-adaptable environments for computer-supported collaborative learning within STEM curricula. As subject to the chronology of events, highlights of the White Paper's outcomes will be showcased within the poster itself.

Collaborations during this workshop identified near-term and future research directions to facilitate adaptable digital environments for highly-effective, rewarding, and scalable team-based learning. An emphasis of the workshop included the personalization of collaborations among diverse learners by automating the identification and utilization of learners' efficacies and knowledge gaps to create complementary collaborative teams that maximize avenues for peer teaching and learning. The workshop targeted the utilization and efficacy of next-generation learning architectures through a focus on instructional technologies that facilitate digitally-mediated team-based learning. These included technical objectives of: (1) identifying new research in learning analytics required to automate more optimal composition, formation, and adaptation of learner design teams; (2) detecting advances in physical and virtual learning environments that can achieve more effective and scalable observation and assessment of learner teams in real-time; (3) distinguishing data mining techniques to leverage devices such as monitors, trackers, and automated camera observations to increase efficacy of team learning; and (4) extending collaborative learning technologies to broaden participation and achievement of diverse learner groups, including women and other underrepresented and underserved populations in STEM. The poster will present the results of the workshop for the design, development, implementation, and evaluation of digitally-mediated teams.

1.0 Introduction

As a joint effort between the University of Central Florida, the Worcester Polytechnic Institute, and the Colorado School of Mines, the Digitally-Mediated Team Learning (DMTL) workshop took place at the University of Central Florida between March 31st and April 2nd of 2019. The purpose of this workshop was to convene researchers, educators, and practitioners to advance transformative pedagogical approaches for technology-enhanced team learning within STEM disciplines at both the secondary and college-level. Further, interdisciplinary data science and STEM researchers, developers, and educators identified future research directions towards adaptable digital environments for effective and scalable team-based learning in classroom settings, with a focus on personalized learning for diverse learners.

The effort was supported by the National Science Foundation (NSF) Division of Research on Learning (DRL) initiative "NSF-18-017: Principles for the Design of Digital Science, Technology, Engineering, and Mathematics (STEM) Learning Environments" [1] through grant DRL-1825007 "Synthesis and Design Workshop: Digitally-Mediated Team Learning" [2]. The objective of this workshop was to determine one-year, three-year, and five-year plans for key research and practice considerations related to the integration of highly-adaptable digital learning environments in STEM teaching and learning, as outlined in a White Paper commissioned by NSF on those topics. The White Paper provided a unifying roadmap for the future of the field, including the design, development, implementation, and evaluation of digitally-mediated team-based pedagogies, and was composed jointly by the organizers and participants of the workshop, to capture the essence of the diverse interactions taking place during the workshop.

1.1 Vision of Change

Team design, *group problem solving*, and *project collaboration* have always been prominent, and even defining, attributes of STEM education, as common labs, projects, and even Senior Design courses, rely heavily on team-based learning. Especially in the last two decades, and into the foreseeable future, team design skills are receiving increasing focus as the complexity of science and engineering marches ever forward [3]. This rising tide of complexity necessitates future graduates within STEM fields to function effectively as specialists who work together closely with diverse populations during product development and research. Thus, the advancement of both mobile and forward-looking educational technologies demonstrating the potential to support team-based instruction is vital and broadly-impacting across STEM fields.

The goals of this workshop were pursued through the following vision of change:

> ***Advance next-generation learning architectures by convening researchers, developers, and educators to participate in the following four synergistic workshop tracks for team-based instructional innovations:***
>
> > ***Track 1: Facilitating Team Learning in Real-time via Online Technologies***
> >
> > ***Track 2: Personalizing Collaborative Learning through Analytics***
> >
> > ***Track 3: Supporting Digital Teams using Active Pedagogical Strategies***
> >
> > ***Track 4: Empowering Equitable Participation through DMTL***

The track-based organization of the DMTL Workshop maximized the likelihood of reaching the needs of every learner by explicitly targeting all aspects of the team-learning process. Tracks 1 and 3 focused on identifying specific technological applications and pedagogical strategies to support the delivery of high-quality team-based instruction, with an emphasis on real-time monitoring of student performance: Track 1 focused on developing new technological platforms, or leveraging existing platforms to achieve this goal, while Track 3 focused on embedding proven and emerging pedagogical strategies in team-based learning. Track 2 sought to optimize the initial team formation based on the learner profile (strengths and weaknesses) of each student, as established through data mining of assessments. Finally, Track 4 focused on developing strategies for equitable learning and inclusion of all students, especially those who may traditionally be underserved or underrepresented in STEM fields. The track-based approach was expected to convene experts from already-established fields, such as Computer-Supported Collaborative Learning (CSCL), Team-Based Learning (TBL), and Learning Analytics (LA), who may rarely attend conferences outside of their specialization, with the goal of both broadening the views of the participants and producing synergy both within and between workshop tracks.

1.2 Outline of Manuscript

Section 2 of this paper will outline the participants' recruitment process for the DMTL Workshop; Section 3 will provide a comprehensive overview of the Workshop purpose, tracks, and activities; Section 4 will present the template-based approach implemented as a tool for organizing Workshop flow and organization of data for integration into the NSF Whitepaper; and finally, Section 5 will present outcomes obtained to date and conclude the paper.

2.0 Promoting Workshop Participation and Recruitment Strategies

A variety of measures were taken by the workshop organizers to publicize the workshop and recruit expert participants. These efforts included the creation of a website and social media channel, development and maintenance of a continually evolving mailing list, use of an expertise profile and position abstracts, and awarding of travel stipends to eligible participants.

2.1 Publicity Mechanisms

To begin the publicizing of the DMTL Workshop, a website was established (see https://www.digital-learning-teams.com/). The website included a variety of Workshop details, including a general overview, descriptions of the scope of each track, invited speakers, a Workshop agenda for each day, and FAQ's. This information was provided as concise text and organized in such a manner that potential participants could quickly determine whether the scope of the Workshop has relevance to his or her discipline. The website also provided a detailed account of the application and registration process for the Workshop (summarized in a flow chart).

To publicize the website, a mailing list of experts who may potentially be interested in participation was developed, updated, and maintained throughout the recruitment process. The mailing list primarily consisted of authors of recent journal/conference papers in fields such as

CSCL, TBL, LA, Learning Sciences, etc., as well as participants on existing listservs relating to areas associated with digitally-mediated team learning. Compiling the mailing list required several hours of research as well as necessary connections with editors/leaders in these fields; however, it was an essential task as it allowed the program committee to reach over one thousand potential participants. Mailing list members were sent an e-mail briefly describing the impetus for, and the nature of, the DMTL Workshop along with a link to the previously described website, where they were able to access additional information. The e-mail was sent twice, once well in advance of proposal priority deadline, and again just before the priority deadline. A formula-based tracking spreadsheet was maintained to keep track of inquiries, participant responses, and management of the content and dissemination of future e-mails.

2.2 Provision of Travel Stipends

As a tool for incentivizing expert attendance and participation at the workshop, 50 travel stipends were offered to eligible participants (i.e., U.S. citizens or permanent residents, per U.S. government regulations). The stipend amount was established at $500 to cover the cost of travel, lodging, and meals for in-state attendees, and $800 for out-of-state attendees. The condition for being awarded a travel stipend was the submission of a position abstract, outlining a topic of expertise relevant to at least one of the four workshop tracks. With the provision of the stipend, three registration deadlines were set: a priority deadline, followed by a regular deadline for stipend consideration, and then a final deadline for all participants, regardless of whether a stipend was awarded.

2.3 Registration Flow

The registration flow differed for participants and was dependent upon whether a travel stipend was requested. If no stipend was requested, participants were required to only complete an expertise profile, gauging their level of expertise as related to at least one workshop track. However, if a travel stipend was requested, applicants needed to develop and submit a position abstract and, once the stipend was granted, submit a W9 form to receive funds. All selected

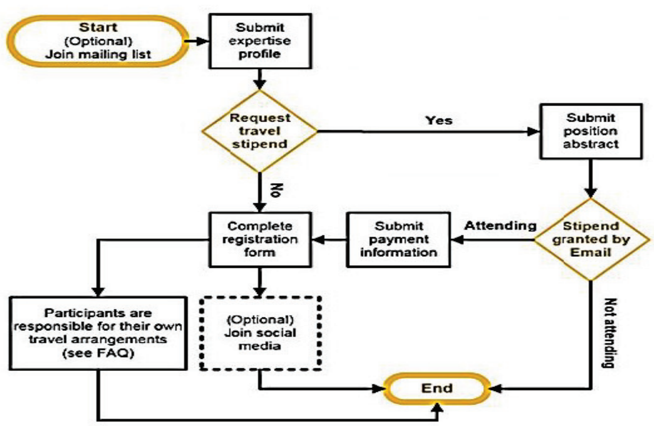
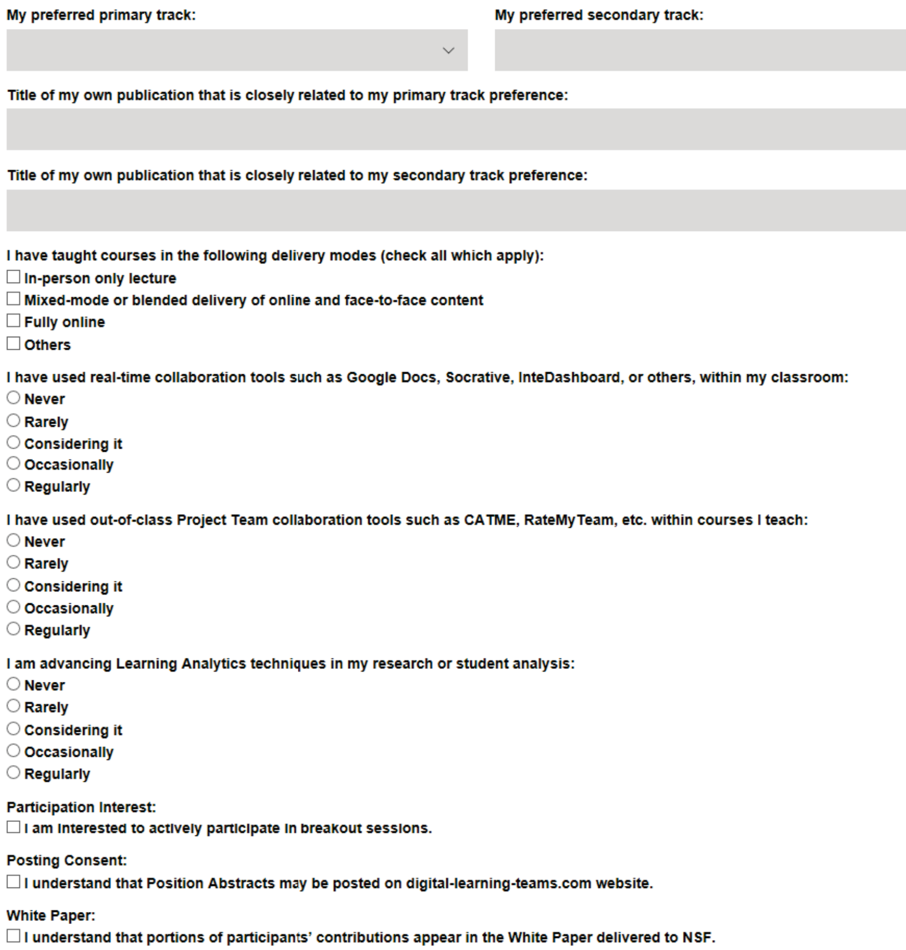


Figure 1: Registration Flowchart.


My preferred primary track:

My preferred secondary track:

Title of my own publication that is closely related to my primary track preference:

Title of my own publication that is closely related to my secondary track preference:

I have taught courses in the following delivery modes (check all which apply):

☐ In-person only lecture
☐ Mixed-mode or blended delivery of online and face-to-face content
☐ Fully online
☐ Others

I have used real-time collaboration tools such as Google Docs, Socrative, InteDashboard, or others, within my classroom:

○ Never
○ Rarely
○ Considering it
○ Occasionally
○ Regularly

I have used out-of-class Project Team collaboration tools such as CATME, RateMyTeam, etc. within courses I teach:

○ Never
○ Rarely
○ Considering it
○ Occasionally
○ Regularly

I am advancing Learning Analytics techniques in my research or student analysis:

○ Never
○ Rarely
○ Considering it
○ Occasionally
○ Regularly

Participation Interest:

☐ I am interested to actively participate in breakout sessions.

Posting Consent:

☐ I understand that Position Abstracts may be posted on digital-learning-teams.com website.

White Paper:

☐ I understand that portions of participants' contributions appear in the White Paper delivered to NSF.

Figure 2: Excerpt of the Expertise Profile

applicants were also required to submit an online registration form, which simply confirmed all dates in which they were available to participate. For the convenience of applicants, a flowchart illustrating the registration flow (Figure 1) was made available on the website.

2.4 Expertise Profile

The expertise profile was available as an online form on the DMTL website, and it was required that all applicants completed the form to gauge both their qualifications to participate in the Workshop and their ability to contribute to the White Paper. The expertise profile requested basic applicant information and requested the selection of at least one Workshop track to focus

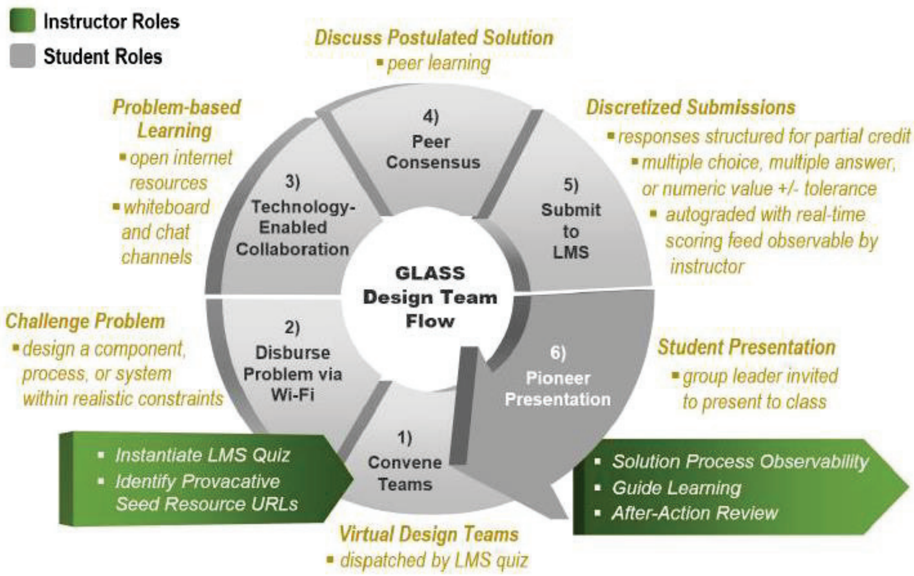


Figure 3: Sequence of DMTL instructor and student roles.

their participation. To demonstrate competence in this track area, applicants were asked to cite at least one of their publications that related to the aim and scope of their selected track. Finally, the applicants were asked a series of survey questions regarding the level of their knowledge and use of educational technologies, learning analytics, emerging and innovative pedagogies, etc. Additionally, the expertise profile confirmed the applicant's interest to participate in all workshop activities (including contributing to the White Paper) and requested their interest in receiving a travel stipend. Figure 2 shows a portion of the expertise profile.

2.5 Position Abstract

Position abstracts were required from all participants requesting a travel stipend. The position abstract provided more in-depth information about an applicant's qualifications, beyond the expertise profile, thus allowing the Program Committee to select the most qualified applicants for the 50 available travel stipends. Besides aiding in the selection process, position abstracts were also used for shaping the workshop agenda, identifying relevant panelists and speakers, and contributing directly to the White Paper. The following instructions, outlining the requirements and considerations for position abstract development, were provided to all applicants:

Position Abstracts should begin by describing the authors' current and planned research, then extend it to recommend approaches that improve the community's shared understanding of DMTL. All Position Abstracts should address the following essential questions:

I. Key Challenges: Which challenge(s) related to digitally-mediated team learning does this Position Abstract address?

II. Maturity: Has the approach been implemented? Under what circumstances? What were the outcomes thus far (in terms of learning gains, student perception, etc.)?

III. Research Direction: What is the promising research direction for this topic?

IV. State-of-the-Art: Across the community, what is the current state-of-the-art for this research direction?

Further, a downloadable template for the position abstract was provided for all participants and was accessible from the DMTL website. Applicants were required to include one to three pages of text related to the four essential questions. Upon completion, applicants were to upload their document through the EasyChair conference management system. Each abstract was then assigned to a Program Committee member, based on track, who then reviewed the abstract and determined whether an offer of a travel stipend was warranted. Those who were not offered a travel stipend were still eligible to attend, and received a link outlining the registration process.

3.0 Overview of DMTL and the DMTL Workshop

3.1 Opportunities for DMTL to advance STEM Learning

The current research in DMTL was initiated as a synchronous problem-based learning spin-off of a project on lockdown digitized assessment conducted by the Investigators [4]. The current research was initiated to investigate viable approaches to integrating student design teams into in-class activities to obtain and acquire the skills required to *design a system, component, or process*, and to *function on multi-disciplinary design teams*, which are an ABET accreditation criteria for engineering degree programs. As depicted in Figure 3, DMTL utilizes one such problem-based learning approach, whereby students acquire expertise while applying skills in solving open-ended problems based upon some trigger content. Further, an increase in proficiency in multidisciplinary design teams was sought by immersing students in alternate problem-solving strategies of their peers, while simultaneously encouraging the development of team interaction and other soft skills. The primary objective of DMTL is to provide students and instructors with an effective technological and pedagogical framework for use during large group instructional sessions. In addition to the benefits to the learner, DMTL provides the instructor with a dynamic view of the learning process, student conceptualizations of content, and challenges associated with specific topics. This information allows the instructor to intervene and reiterate, elaborate, and reinforce concepts that require attention, perhaps by providing additional explanation or examples. DMTL also assists instructors with managing time more effectively and efficiently within the whole-group instructional session, while also gaining more in-depth knowledge and understanding of unique attributes of student problem-solving approaches.

Recently, numerous technology-based tools have become available to facilitate real-time, in-class online collaborations [5-9]. The integration of some of the most rudimentary of these tools, such as Online Collaborative Document/Spaces (e.g. Etherpad) and LMS-based tools (e.g., Canvas, Moodle), into teaching and learning environments are becoming increasingly ubiquitous. Etherpad, for example, is a free, collaborative online text-based editor, allowing

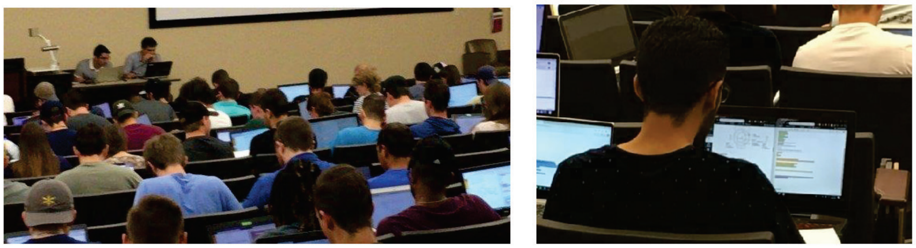


Figure 4: (Left) Instructors and students conducting a DMTL Activity; (Right) Student uses Etherpad within a computer-supported collaborative learning exercise during the authors' undergraduate course face-to-face meeting session.

participants to edit text documents simultaneously while also seeing edits of collaborators, in real-time. Etherpad displays each participant's communication using a unique font highlighting color so that their contributions are differentiated and color-coded, alongside a chat window, which allows for live discussions during the text editing process. One feature of Etherpad that is valuable for design teams is that color-coded traceability allows for documentation of individual contributions throughout the team-based learning event.

Furthermore, Etherpad does not require students to sign-up for an account to utilize the tool, resulting in decreased logistics for classroom integration. Traceability, built-in chat windows, customization for enabling/disabling collaborative annotations, and other functionality are critical technological features for the facilitation of DMTL. The instructor facilitates the DMTL flow by constructing the team learning activity through the creation of an assessment within the course's existing LMS assessment tool. Once a design team concurs that their results are complete, they submit their answers to the Learning Management System (LMS) for auto-grading and score-recording in the grade book. Credit is earned by correctly answering each designated question sub-part, which provides partial credit, a critical aspect of questioning in STEM. Throughout the team design activity, the instructor monitors assignment progress online in real-time, including windows for each design team, illustrating a solution draft as it is constructed, and allowing for providing feedback via each group's designated chat channel. Figure 4 (right) shows a student using Etherpad and the course LMS to share resources, discuss their approach to the problem, and reach a consensus when ready to submit for grading. Figure 4 (left) shows students conducting DMTL with their laptop, with instructors and GTAs guiding students from the front desk.

3.2 DMTL Workshop Overview

The two-and-a-half-day workshop addressed the design, development, implementation, and evaluation of DMTL in the K-20 educational landscape. The workshop flow which was used is outlined in Figure 5. The initial half-day of the workshop consisted of technical overview and networking activities which commenced on Sunday afternoon. These included an optional poster session for those wishing to present their Position Paper in a poster format. The poster session also provided an optional social mixer while allowing other participants to arrive into Orlando that evening. On Monday, the Workshop sessions commenced after a keynote address spanning

3.3 Intellectual Merit and Broader Impacts of the DMTL Workshop

The DMTL Workshop coalesced significant knowledge related to the utilization of learner design teams in instructional settings. As mentioned, its tracks have informed both near-term and future research related to: 1) harnessing learning analytics in STEM for optimal team formations; 2) real-time observation and assessment with learner teams; 3) data-mining tracking and monitoring data for team learning; and 4) broadening and strengthening the participation of underrepresented populations in team learning. The explorations and subsequent outcomes related to these topics are of significant interest to STEM researchers, educators, and practitioners, as they possess potential to inform the development of scalable, sustainable, and transportable educational solutions for developing team learning through digital means. The White Paper and other dissemination efforts (website, conference presentations, journal publications, etc.) resulting from the DMTL Workshop provide a roadmap for future STEM research related to the design, development, implementation, and evaluation of digitally-mediated teams in diverse instructional settings. Further, the outcomes of this workshop could lead to the advancement and development of new and emerging educational approaches in STEM teaching and learning.

The broader impacts of the DMTL Workshop directly connect to both national and societal goals of improving STEM instruction to develop a stronger national STEM workforce. The workshop united faculty and related industry leaders with expertise in various STEM subjects, including Data Analytics, Data Mining, and Instructional Design & Technology, as well as underrepresented populations, with the goal of identifying pedagogical approaches to facilitate and strengthen digitally-mediated team learning. The workshop contributed to future cross-networking and co-constructing among the attending experts, as they continue to investigate aspects of digitally-mediated team development in STEM. Workshop activities resulted in the previously mentioned White Paper, an Executive Summary, infographic, images, videos and a website to maximize the outreach of themes addressed during the workshop. The constructive broader impact of the resulting White Paper was its highlighting of technical topics to be prioritized for future funding to advance the competitiveness of the U.S. with respect to STEM education and economic vitality. Dissemination of the findings from the workshop include social, traditional, and popular media outlets, and the outcomes of the workshop will benefit researchers, educators, and practitioners from multiple disciplines. Further reaching, the public will be informed of digitally enhanced systematic approaches for forming and designing digitally-mediated design teams in STEM that will broaden underrepresented participation.

The social media plan for disseminating information involved Twitter and YouTube. Hashtags for the workshop appeared on the workshop website. In the three months prior to the event, anticipation posts were made which included some of the hashtags of NSF and the NSF CIRCL Center. As derived from the workshop, the event videos were posted to the outcomes of the research and work being conducted. Due to multi-disciplinary and multi-university representation, the social media dissemination influenced a broad and crosscutting release. Through a pre-established internship program, a social media and digital media undergraduate student implemented the plan.

Table 1: Anticipated data collection metrics and their corresponding objectives.

Approach	Objective	Follow-Up	Data Type
Verbal Interaction Diagrams	Social process Interaction	Analyzed for equitable participation	Round table diagram protocol - quantity and flow of interaction
Discourse Observation Protocol	Leadership/Observer/ Participant	Identify consensus on topic priorities	Quality and types of interactions protocol
Video	Content Analysis Interactions to Triangulate Quantitative Data and Outcome Paper	Available in the event of missing data regarding recommendations from track	Content Analysis for Themes and Interactions
Daily Survey (After each Day)	Formative and Summative Assessment of Interaction and Progress	Tracked and reported in White Paper	Likert Scale Open-Ended Response
One-Minute Cards	Unanswered Questions and Summary Cards	Verify with Track chair for resolution	Open-Ended Response

Table 1 lists the types of information that was collected from the workshop, which included: the position papers of participants, discourse process data, video, and participant's reflection. Collection and analysis of both qualitative and quantitative data provided a detailed understanding of the process and dynamics of the workshop, as well as helping to realize its outcomes. Novel data collection techniques were leveraged to gather the desired information from the workshop using video tracking. These were developed into an observation protocol to collect qualitative data on the social processes observed, as well as supervision of the analysis of the process and interaction data.

3.4 DMTL Workshop Track Outlines

This section identifies the guiding questions in each track, as well as track aims and scope.

3.4.1 Track 1: Facilitating Team Learning in Real-time via online Technologies

The focus of Track 1 included the facilitation of team learning in real-time via online technologies. Primary topics of Track 1 included the following:

- Design of online instructional environments for engaging, observing, and assessing STEM design and problem-solving teams in real-time;
- Specification of instructional technologies that enhance the traceability of activities within learner teams, advanced mechanisms for integrated and automated scoring, and annotation/organization of feedback; and
- Identification of standardized interfaces for learning management systems and defining/outlining characteristics of transportable formats/clearinghouses for problem banks.

Sample guiding questions for Track 1 included:

- How is the interaction between the instructor and student teams supported when using the proposed real-time collaborative technologies?
- What platforms (e.g., Canvas, Socrative, Edupad) are being targeted with this approach? How can strategies be made adaptable to different platforms?
- How are students being monitored/graded in real-time? What is the cost (e.g., in terms of grader hours) of scaling up to a larger setting?

Theme 1A: Activity Authoring

- Which types of STEM design and problem-solving activities are envisioned and some archetypes?
- Which of those archetypes are prioritized at 1,3,5 years to leverage a layered development flow?
- How to create clones, handle solution visibility, and content reuse?
- Is a Respondus-style converter facility helpful to create/maintain authored activities?

Theme 1B: Student-Facing Delivery

- What would suitable and even the ideal student-facing user interfaces for DMTL look like?
- What are essential widgets for a student-facing interface: e.g. raise hand, bannering, balloting, pin note, up-voting?
- How do learners nominate team leaders or MVPs? e.g. pick lists, ratings, blinded vs. open, or support a range of options?
- What are some state-of-the-art tools today for DMTL to consider for further inspiration?

Theme 1C: Instructor Orchestration

- How should instructor-facing user interfaces for DMTL operate and which features would they provide?
- How to support instructor observability/moderation of individual teams and the overall activity, and what are 'operator loading limits' to do so?
- After action review should have which features? e.g. are playback and freeze modes of session activities beneficial?
- Which Team Management features from semester-long team project management tools are applicable to 30-minute synchronous DMTL activities in the classroom, e.g. CATME features?
- What parameters should be specified? e.g. number of teams, activity duration, etc.?

Theme 1D: Educational Games

- How does DMTL relate to Educational Games? e.g. attributes in common, compare/contrast?
- Which progress achieved / features in Educational Games can be most useful to apply to DMTL?
- What is the role of VR to conduct DMTL activities in the near and long term?
- Can we describe a 'best application' of Games/VR for DMTL?

Theme 1E: Assessment Mechanisms

- Team vs. Student Scoring Resolution, e.g. is there benefit in providing student-level traceability?
- Which capabilities can be feasible for automation of scoring? And mechanisms to realize those?
- What would constitute Real-time Dashboard Display content vs. static summary report content?
- How to determine correctness, time-on-task, and identification of pioneer teams automatically?
- How to annotate/organize/provide feedback on submissions?

Theme 1F: Standards & Clearinghouses

- What are preferable mechanisms and interfaces needed for effective LMS integration of DMTL?
- Definition of transportable formats: will they help to interchange activity content? and results?
- Clearinghouses for problem banks: what, where, when?
- Symposia: crosslinking sessions in which conferences? CSCL, CSCW, EDM, ASEE, AERA, etc.

Figure 6: Themes in Track 1 and their corresponding Guiding Questions.

3.4.2 Track 2: Personalizing Collaborative Learning through Analytics

The focus of Track 2 was the personalization of collaborative learning through analytics. Primary topics of Track 2 included the following:

- Utilizing offline data-mining of assessments for automated optimization of team composition and sustained back-end reporting of learning outcomes;
- Collecting and leveraging real-time observations of team member participation, dynamically identifying learners needs/ZPD, restructuring learner cohorts, and generating instructor/learning guidance on-demand; and
- Defining metrics, benchmarks, and repositories for the evaluation and interchange of worthwhile algorithms and techniques to advance analytics of effective learning teams.

Sample guiding questions for Track 2 included:

- How can student formative assessment data be used to optimize student learning teams?
- What are prototypical platforms, and key functionalities of these platforms, available to rapidly and optimally form and convene student teams?

3.4.3 Track 3: Supporting Digital Teams using Active Pedagogical Strategies

The focus of Track 3 was the exploration of mechanisms to support digital teams via active pedagogical strategies. Primary topics of Track 3 included the following:

- Defining pedagogical strategies for technology-enhanced active learning to support synchronous student team-based events;
- Underpinning the team activities within STEM classroom settings via cognitive science, including peer interactions, intrinsic/extrinsic incentivization, and lurker/lone wolf interactions; and
- Exploring andragogical/pedagogical methods leading to auto-gradable/reusable/scalable problem design, Individual/Team Readiness Assessment Tests (IRAT/TRAT), Most Valuable Peer (MVP) protocols, and actionable lesson plans.

Sample guiding questions for Track 3 included:

- What pedagogical strategies support the engagement of all learners in team-based learning?
- Which pedagogical strategies minimize challenges typically associated with team-based learning?
- Which pedagogical methods support the assessment of the contributions/achievement of individual students when utilizing team-based learning?

3.4.4 Track 4: Empowering Equitable Participation through DMTL

The focus of Track 4 was related to empowering equitable participation of diverse learners through DMTL. The scope of this track included:

- Fostering collaborative digital learning approaches that broaden participation among underserved and underrepresented populations;
- Investigating the role of socially-agnostic participation: neutral from observation (no preconceptions), and also neutral from some aspects of active projection (reduced dominance from interpersonal tone)

- Providing mechanisms to elevate retention and achievement through personalization-supporting diverse learners in collaborative settings across multiple disciplines in STEM.

Sample guiding questions for Track 4 included:

- How can DMTL support participation and achievement of underrepresented students in STEM?
- What approaches can be taken to reduce social barriers among students that may be underrepresented in the STEM population?
- What approaches can be taken to give equal opportunity to students who may have difficulty participating in team activities (e.g., due to personality, disability, etc.)?

4.0 Template-Based Participation Flow

To maintain participants' focus during the workshop, each track was divided into 4 – 6 themes (see Table 2), which were selected based on the position abstracts received. To ensure that each theme was addressed comprehensively, while also managing and focusing the track discussions, the workshop was divided into a series of one-hour breakout sessions, with each breakout session being devoted to a particular theme (on day 1). To facilitate engagement and discussion, participants are provided with a template for each theme, in which they were to identify key concepts, areas of concern, and emerging points of discussion, which would in turn, be used to populate the White Paper.

4.1 Designation of Themes

As mentioned, participants were provided with guiding questions specific to each track. This approach was mirrored regarding each theme, with discussions for each theme being driven by a series of guiding questions, which were useful in also clarifying the primary aims and scope of each theme. A sample set of guiding questions for Track 1 themes is identified in Figure 6.

4.2 Template Boilerplate

To support the overall goals of the workshop and facilitate the development of the white paper, one-page templates were provided to participants during each breakout session (see Figure 7). The focus of template use was the drafting of key aspects of the discussion surrounding each theme, particularly in response to each guiding question, which was then be used to inform the finalization of the White Paper. As a tool to support familiarity with the process and interactions for each track discussion and breakout session, the templates were identical, except for the track name and theme.

Table 2: Workshop Tracks and Themes

	Track 1	Track 2	Track 3	Track 4
Theme A	Activity Authoring	Types of Learner Data (e.g., speech, biometrics)	TPACK in DMTL	Factors of Engagement
Theme B	Student-Facing Delivery	Assessment Mechanics (analytic approaches for literally noisy data)	Engagement & Accountability	Fostering Inclusivity
Theme C	Instructor Orchestration	Challenges for Optimization of Group Learning	Team Management	Equity & Diversity
Theme D	Educational Games	Using Data to Provide Feedback	Emerging Pedagogies	Transferability & Sustainability
Theme E	Assessment Mechanisms	Enhancing Cognitive Demand and Mastery of Learning Outcomes	Faculty & Student Orientation	Possibilities of DTML

Theme 3E: Faculty and Student Orientation

- **State of the art** for this theme:
- Some **challenges** for this theme:
- **Key works** related to this theme (5 to 10 citations):
- **1-year** research objectives:
- **3-year** research objectives:
- **5-year** research objectives:

Figure 7: Sample Template used during Breakout Sessions.

Figure 8: Collaboration facility for Breakout Sessions.

Table 3: Attendee Institutions.

- Carnegie Mellon University
- Colorado School of Mines
- Concord Consortium
- Duke University
- Embry-Riddle University
- Florida State University
- George Mason University
- Georgia State University
- Georgia Tech
- Harvard University
- Indiana University
- McGraw Hill Education
- New York Hall of Science
- New York University
- North Carolina State Univ.
- Oregon State University
- Pennsylvania State Univ.
- Pepperdine University
- Purdue University
- Rutgers University
- St. John's University
- Syracuse University
- Texas Tech University
- UCLA School of Medicine
- University at Albany
- University of Calif., Irvine
- University of Central Florida
- University of Florida
- Univ. of Hawaii West Oahu
- Univ. of Wisconsin-Madison
- University of Michigan
- UNC Charlotte
- University of North Texas
- University of Portland
- University of San Diego
- Univ. of South Carolina
- Univ. of South Florida
- University of Tampa
- Univ. of Texas at Arlington
- University of Texas at Tyler
- University of Washington
- University of Wyoming
- Virginia Tech
- Worcester Polytechnic Inst.

4.3 Breakout Session Organization

The workshop was partitioned into nine 1-hour breakout sessions (five on the first day, and an additional four on the second day), each taking place in state-of-the-art conference rooms within the Morgridge International Reading Center at the University of Central Florida (shown in Figure 8). During a breakout session, participants attended one of concurrent four sessions, corresponding to their track, with each session designed to address a specific track theme. At the beginning of each session, a shared document version of each track theme's template was shared with each participant and was to be edited collaboratively with other members of their track. To facilitate focused and constructive discussions, and to eliminate rogue and off-topic discussions (which was difficult due to the diverse and expansive expertise among track participants), a designated track leader served as a moderator and timekeeper for each breakout interval. Breakout sessions were designed to advance toward defining the aims and scope of the theme, using the theme's guiding questions as a roadmap. While these initial steps consumed a few minutes, they were useful in ensuring that the remaining time in the initial session, as well as subsequent sessions, was used productively.

At the end of the first day, the templates filled out by workshop participants were mined and served as an outline for the White Paper. On the second day, participants used their time to once again look over the templates resulting from the Day 1 breakout sessions, and used the Day 2 breakout sessions to both extend and refine ideas via an approach that has been effective in industrial settings [10]. To encourage comprehensive discussions, and to maximize the extensive and diverse expertise, participants were encouraged to switch tracks for some of the Day 2 breakout sessions. Upon finalization of the concepts and ideas for each track, track members, led by track co-chairs, began drafting the narrative of the White Paper, to be completed after the workshop ended and, subsequently, presented to NSF.

5.0 Conclusion

The DMTL Workshop was sponsored by NSF, the Helmsley Charitable Trust, McGraw Hill Education, and

UCF's College of Graduate Studies. Over 600 emails were sent in support of participant recruitment efforts. In addition, several e-mail distribution lists were used, including ASEE, CIRCL, and TBLC, each of which sent Workshop recruitment information to their members. In total, 86 participants registered from more than 40 institutions, as listed in Table 3. Participants included five panelists, four keynote speakers, nine workshop organizers, and approximately 20 local attendees from the UCF community. Approximately 50 stipends were awarded to U.S. citizens/permanent residents, including keynote speakers and numerous experts in several fields associated with DMTL. Moreover, more than 30 position abstracts and over 60 expertise profiles were received. Several DMTL-related companies and organizations attended the Workshop, including those showcasing the CATME Smarter Teamwork [11], Collabrify [9], Idea Thread Mapper (ITM) [12], and InteDashboard [13] frameworks. Lastly, the workshop brought together diverse DMTL communities, such as those who publish in venues of Computer-Supported Collaborative Learning, Computer-Supported Collaborative Work, and the International Society of Learning Sciences. The results of the Workshop were disseminated via social media outlets, a program website, and in the final version of the White Paper, which was delivered at the NSF summit on Future Digital STEM Learning Environments which was convened upon completion of the nine workshops conducted through NSF-18-017.

Acknowledgements

This effort was supported by the National Science Foundation (NSF) Division of Research on Learning (DRL) initiative "NSF-18-017: Principles for the Design of Digital Science, Technology, Engineering, and Mathematics (STEM) Learning Environments" [1] through grant DRL-1825007 "Synthesis and Design Workshop: Digitally-Mediated Team Learning" [2]. Additional funding, listed alphabetically, was provided by the Helmsley Charitable Trust, McGraw Hill Education, and the UCF College of Graduate Studies.

References

[1] "Synthesis and Design Workshop: Digitally-Mediated Team Learning," NSF Project DRL-1825007, Retrieved from: https://www.nsf.gov/awardsearch/showAward?AWD_ID=1825007

[2] "Dear Colleague Letter: Principles for the Design of Digital Science, Technology, Engineering, and Mathematics (STEM) Learning Environments," NSF DCL 18-017, Retrieved from: https://www.nsf.gov/awardsearch/showAward?AWD_ID=1825007

[3] J. W. Lin and Y. C. Lai, "Harnessing Collaborative Annotations on Online Formative Assessments," *Journal of Educational Technology & Society,* Vol. 16, No. 1, pp. 263 - 274, 2013.

[4] R. F. DeMara, N. Khoshavi, S. Pyle, J. Edison, R. Hartshorne, B. Chen, M. Georgiopoulos,"Redesigning Computer Engineering Gateway Courses Using a Novel Remediation Hierarchy," in *American Association for Engineering Education National Conference (ASEE-16)*, New Orleans, LA, USA, 2016.

[5] R. F. DeMara, S. Salehi, B. Chen, and R. Hartshorne, "GLASS: Group Learning At Significant Scale via WiFi-Enabled Learner Design Teams in an ECE Flipped Classroom," in *Proceedings of American Society for Engineering Education (ASEE) Annual Conference & Exposition,* Columbus, OH, USA, June 26-30, 2017.

[6] M. Sanders, S. Spiegel, and J. Sherer, "Moving Beyond Does Active Learning Work?" with the Engineering Learn-ing Observation Protocol (ELCOT)," in *2018 ASEE National Conference and Exposition*, Salt Lake City, UT, USA, June 24 - 27, 2018.

[7] M. A. Kazemitabar *et al.*, "Creating instructor dashboards to foster collaborative learning in on-line medical problem-based learning situations," in *Proceedings of International Conference on Learning and Collaboration Technologies*, pp. 36-47, Las Vegas, NV, USA, July 15-20, 2016.

[8] S. Lu, L. Lazos, and R. Lysecky, "FEAL: Fine-Grained Evaluation of Active Learning in Collaborative Learning Spaces," in *Proceedings of ASEE Annual Conference and Exposition, Conference*, Columbus, OH, USA, June 26-30, 2017.

[9] C. Norris and E. Soloway, "The Collabrify Research Platform: A research tool for studying synchronous collaboration in the classroom," in *Proceedings of iConference 2017*, Wuhan, China, March 22-25, 2017.

[10] L. Karas and D. H. Rhodes, "3 The Common Denominator," in *Proceedings of INCOSE International Symposium*, Vol. 9, No. 1, 1999.

[11] Misty L. Loughry, Matthew W. Ohland, and David J. Woehr. "Assessing teamwork skills for assurance of learning using CATME team tools," *Journal of Marketing Education*, Vol. 36, No. 1, pp. 5-19, 2014.

[12] J. Zhang, M.-H.Chen, D. Tao, Y. Sun, J. Lee, & D. Judson, D., "Fostering sustained knowledge building through metadiscourse aided by the Idea Thread Mapper. In O. Lindwall, P. Ha´kkinen, T. Koschmann, P. Tchounikine, & S. Ludvigsen (Eds.), *Exploring the Material Conditions of Learning: The Computer Supported Collaborative Learning (CSCL) Conference 2015*, Vol. 1, pp. 166–173. Gothenburg, Sweden: *International Society of the Learning Sciences*.

[13] B. O'Dwyer, "Training the next generation in aviation with technoogy enabled team-based learning," in *Proceedings of 2018 AviAsian Conference*, Singapore, September 5, 2018.

Methods and Outcomes of the NSF Project on Synthesizing Environments for Digitally-Mediated Team Learning (DMTL)

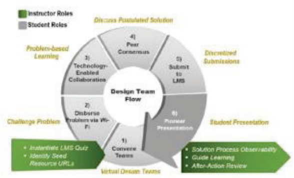
Ronald F. DeMara, Laurie O. Campbell. Richard Hartshorne, Samuel Spiegel, Joseph E. Beck, Zhongzhou Chen, Melissa Dagley, Eloy Hernandez, Tian Tian, Julie Donnelly, Adrian Tatulian, Shadi Sheikhfaal, Hossein Pourmeidani. and Hans Esteves

University of Central Florida

DMTL Overview

What is DMTL?

- Digitally-Mediated Team Learning (DMTL) encompasses **cooperative learning** in a **digital classroom-based synchronous** setting with the instructor in a supportive role.
- Foci of DMTL include **STEM problem-solving and design activities in real-time**, with an emphasis on leveraging *educational technologies*, *learner analytics*, and *pedagogical methods*, while *empowering equitable participation*.



Workshop Goals

Outcome Objectives

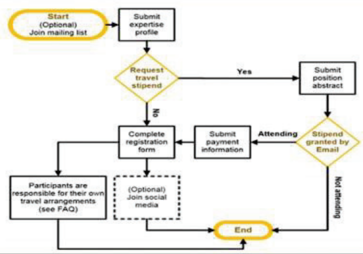
- Identify the **state of the art** in DMTL
- Identify **future research directions** along with **challenges**
- Deliver **white paper** to NSF

Organizational Objectives

- **Recruit** a qualified team of participants
- **Optimize** capture of ideas
- **Maximize** efficiency in the process of writing the white paper

Recruitment with Abstracts responding to Guiding Questions

- **DMTL website (https://www.digital-learning-teams.com):** includes workshop overview, agenda, track descriptions, invited speakers, and FAQs in addition to an easy-to-follow registration flow chart and links
- **Expertise profile:** Gauges qualifications of applicants
- **Position abstract:** Applicants upload a 1-2 page document on a DMTL topic relating to their research, including:
  - Key challenges
  - Maturity
  - Research directions
  - State of the art
- Position abstracts are used to qualify applicants for one of 50 available **travel stipends** to the workshop



Participation

Number of Participants:

- 84 from 44 universities

1) In-Field STEM:

- Senior: 23%
- Junior: 13%

2) Learning Sciences / Specialists:

- Senior : 27%
- Junior : 29%

3) Doc Students: 8%

Template-Based Flow

Workshop Timeline

Pre-Activities (October 2018 - March 2019): Expertise Profiles; Position Abstracts; Track Talking Points

Workshop (March 31 – April 2, 2019, Orlando, FL):

- Sunday 31 March 2019 — Starting 3pm: Poster Session; Demos; Industry Tables; Social Mixer
- Monday 1 April 2019 — Keynote; Workshop Overview; Parallel Tracks 1 → 4; Lunch; Parallel Tracks 1 → 4; Panel; Tours
- Tuesday 2 April 2019 — Keynote; Debrief; Parallel Tracks 1 → 4; Lunch; Parallel Tracks 1 → 4; Action Committee Formation

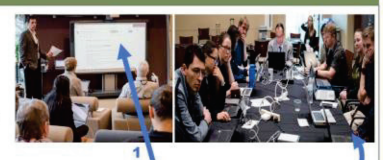
Qualitative Observation Protocol & Quantitative Data Analysis

Post-Activities (April 2019 - June 2019): Action Committee Chapter Drafts → White Paper → NSF Summit

Technical Topics

- **Four tracks** with **five themes** per track with **guiding questions** collaborated on via Wi-Fi
- **Allocation of one hour per theme** as timed activity to harness expertise evenly on all topics
- .**Designated Moderator** leads each theme.

	Track 1	Track 2	Track 3	Track 4
Theme A	Activity Authoring	Types of Learner Data (e.g. speech, biometrics)	TPACK in DMTL	Factors of Engagement
Theme B	Student-Facing Delivery	Assessment Mechanics (analytic approaches for literally noisy data)	Engagement & Accountability	Fostering Inclusivity
Theme C	Instructor Orchestration	Challenges for Optimization of Group Learning	Team Management	Equity & Diversity
Theme D	Educational Games	Using Data to Provide Feedback	Emerging Pedagogies	Transferability & Sustainability
Theme E	Assessment Mechanisms	Enhancing Cognitive Demand and Mastery of Learning Outcomes	Faculty & Student Orientation	Possibilities of DTML



Collaboration Template

Track 1: Facilitating Team Learning in Real-time via Online Technologies
Theme 1C: Instructor Orchestration (Ron)
State of the art for this theme:
Some **challenges** for this theme:
Key works related to this theme (5 to 10 citations):
1-year research objectives:
3-year research objectives:
5-year research objectives:

Recommendations

Imm: Unify research evidence on efficacy of *real-time classroom-based DMTL across delivery modalities* (e.g. co-located, synchronous-but-seated-separately, and mobile-devices) via studies and workshops.

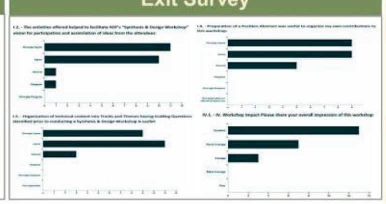
NT: Create *reusable and adaptable DMTL activities with engaging learner interfaces* supporting STEM- specific tools (e.g. models, programming, equations, simulations) with *analytics for personalization and instructor orchestration of cooperative learning in real-time.*

NT: Create a *Virtual Innovation Center* showcasing high-impact DMTL practices, users, and an adaptable resource repository which leverages methodologies emphasizing interdisciplinary psychophysiological efforts, self-report mechanisms, and inventories to advance inclusivity.

LT: Design *new data science approaches exploring various team formations'* impact on learning outcomes.

LT: Apply and extend *ML/AI technologies within DMTL* to: (a) longitudinally suggest (or automatically construct) team learning activities personalized to the learners at-hand, (b) hybridize DMTL with Intelligent Tutoring Systems (ITS) whereby ITS agents have co-instructor roles, and (c) adapt XR environment to spontaneously insert virtual teammates at pivotal moments, e.g. triggered by wheel spinning / wrong path.

Exit Survey



References

[1] "Synthesis and Design Workshop: Digitally-Mediated Team Learning," NSF Project DRL-1825007, Retrieved from: https://www.nsf.gov/awardsearch/showAward?AWD_ID=1825007.
[2] R. F. DeMara, S. Salehi, B. Chen, and R. Hartshorne, "GLASS: Group Learning At Significant Scale via WiFi-Enabled Learner Design Teams in an ECE Flipped Classroom," *American Society for Engineering Education (ASEE) Annual Conference & Exposition*, Columbus, OH, June 26-30, 2017.

Acknowledgements

Sponsored by NSF DRL-1825007. Additional funding and resources were provided by the Helmsley Charitable Trust; McGraw Hill Education; UCF College of Community Innovation, Education (CCIE); UCF College of Engineering and Computer Science (CECS); and UCF College of Graduate Studies.

Contact

Ronald F. DeMara, Ph.D., P.E.
Department of Elec. & Comp. Engr.
University of Central Florida
Orlando, FL 32816-2362
Email: ronald.demara@ucf.edu
http://digital-learning-teams.com

University of Central Florida

Convened:
March 31, 2019 –
April 2, 2019

Synthesis and Design Workshop: Digitally-Mediated Team Learning (DMTL)

Ronald F. DeMara (PI, UCF), **Laurie O. Campbell** (Co-PI, UCF), **Samuel Spiegel** (Co-PI, Colorado School of Mines), **Richard Hartshorne** (Co-PI, UCF), and **Joseph E. Beck** (Co-PI, WPI)

This material is based upon work supported by the National Science Foundation under grant 1825007. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Driving Question / Purpose

Which research will advance effective and scalable *digital environments* for *synchronous team-based learning* involving *problem-solving and design activities* within *grades 6-20 STEM classrooms* for *all learners*?

1/3/5+ Year Research identified via Four Parallel Tracks

- **T1)** Facilitating Team Learning in Real-time via Online Technologies
- **T2)** Personalizing Collaborative Learning through Analytics
- **T3)** Supporting Digital Teams using Active Pedagogical Strategies
- **T4)** Empowering Equitable Participation

5 Themes per Track

a) Activity Authoring
b) Student-Facing
c) Instructor Orchestration
d) XR/Gamification
e) Indexing

Participants

84 from 44 universities

Carnegie Mellon University
Colorado School of Mines
Concord Consortium
Duke University
Embry-Riddle University
Florida State University
George Mason University
Georgia State University
Georgia Tech
Harvard University
Indiana University
McGraw Hill Education
New York Hall of Science
New York University
North Carolina State Univ.
Oregon State University
Pennsylvania State Univ.
Pepperdine University
Purdue University
Rutgers University
St. John's University
Syracuse University
Texas Tech University
UCLA School of Medicine
University at Albany
University of Calif., Irvine
University of Central Florida
University of Florida
Univ. of Hawaii West Oahu
Univ. of Wisconsin-Madison
University of Michigan
UNC Charlotte
University of North Texas
University of Portland
University of San Diego
Univ. of South Carolina
Univ. of South Florida
University of Tampa
Univ. of Texas at Arlington
University of Texas at Tyler
University of Washington
University of Wyoming
Virginia Tech
Worcester Polytechnic Inst.

In-Field STEM:
Senior: 23%
Junior: 13%

Learning Sciences / Specialists*:
Senior : 27%
Junior : 29%

Doc Students: 8%

* **Including**: Data Sciences, Digital Media, Medicine, MIS, Philosophy, Psychology, Statistics

Sponsorship

- *NSF Division of Research on Learning:* DRL-1825007
- *Helmsley Charitable Trust:* meals, video/media, costs
- *McGraw Hill Ed:* reception
- *UCF CCIE, CECS, & CGS:* resources, costs

Process

Template-Based approach to Digitally-Mediated Collaboration

Workshop Flow & Timeline

Collaboration Template

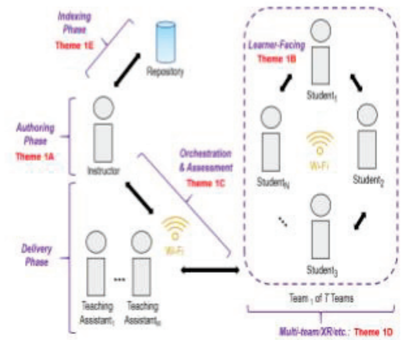
Track 1: Facilitating Team Learning in Real-time via Online Technologies
Theme 1C: Instructor Orchestration (Ron)

State of the art for this theme:
Some **challenges** for this theme:
Key works related to this theme (5 to 10 citations):
1-year research objectives:
3-year research objectives:
5-year research objectives:

Findings

DMTL increasingly vital to the future of Digital STEM Learning

- **Numerous untapped opportunities** for online instructional environments to *engage, orchestrate, and assess* STEM design and problem-solving teams in classroom settings.



- **DMTL researchers seek to integrate/extend** the excellent interdisciplinary work done continuously since the 1980s via *feature-specific research* towards *systems impact* viewpoints.
- **Proven methods, inexpensive technology, and digitally-receptive students combine** for timely feasibility of center-scale grand challenge given widespread adoption of *mixed-mode delivery* and demands of *enrollment scalability.*
- **Attendees unanimous in the value of a roadmap for DMTL** created in a workshop setting with components/interfaces researched and then *integrated / evaluated / refined* spanning pedagogy, team sciences, machine learning, etc.

Principles

DMTL synergizes powerful learning design principles from multiple complementary research domains

1) DMTL leverages instructional technology during group problem-solving activities

a) Learners co-construct solutions to exercises through ways of thinking (e.g. *design*, *computational*, and *systems thinking*).
b) Team members may *adopt technical/leadership roles* and modify those during the activity.
c) Principles of *peer teaching and learning* are enabled.

2) Instructor serves in supportive roles

a) Technology assists instructor *observation and scaffolding* of team progress in real-time.
b) Rapid formative feedback occurs *during the learning exercise* rather than afterwards.

3) DMTL advances equitable participation

a) Inclusivity encompasses the *human aspects in a community of learners*.
b) Consideration and training of *stakeholders with respect to personal and perhaps unconscious biases further increase participation* and sustainability in STEM.

Surprises & Tensions

Tension: Contrasts between K-12 vs. Higher Ed.

- *Origins:* Each domain has been independently advancing DMTL with limited cross-collaboration/exchange.
- *Perspectives:* Contrasting pedagogical knowledge in (K-12 vs. Higher Ed.) & usage in (STEM vs. non-STEM).
- *Differences:* Learner-facing interfaces and assessment benefit from distinct research varying by domain.
- *Constructive Outcome:* Participants commented in the *Workshop Survey* that interactions with diverse disciplines offered new ideas that they could put to work immediately.

Surprise: Unanimous need for Surveys, Standards, and Clearinghouses

- *Conceptual Challenges:* Nomenclature challenges of interdisciplinary roles in DMTL.
- *Existing Systems:* need to identify, classify, relate, adapt, and extend these to progress further, but how?
- *Technology Complexity:* Languages, development platforms, updates/change, and obsolescence.
- *Constructive Outcome:* Opportunity to form taxonomies, researcher-facing compendiums/standards, and instructor-facing web resource sites.

Tension: "Microscope vs. Telescope" (as promulgated by C. Dede)

Recommendations

- Immediate ***(Imm)***, Near-Term ***(NT)***, and Longer Term ***(LT)***
- Based on White Paper / tables, ASEE-2019 manuscript/poster, and Exit Survey

Imm: Unify research evidence on efficacy of *real-time classroom-based DMTL across delivery modalities* (e.g. co-located, synchronous-but-seated-separately, and mobile-devices) via studies and workshops.

Imm: Assemble *glossary of inclusivity terminology, methods, and metrics* relevant to DMTL. Consider potential advances in equitable participation across the range of interactions enabled within digital teams.

NT: Create *reusable and adaptable DMTL activities with engaging learner interface*s supporting STEM-specific tools (e.g. models, programming, equations, simulations) while employing *analytics for personalization and instructor orchestration of cooperative learning in real-time*.

NT: Create a *Virtual Innovation Center* showcasing high-impact DMTL practices, users, and an adaptable resource repository which leverages methodologies emphasizing interdisciplinary psychophysiological efforts, self-report mechanisms, and inventories to advance inclusivity.

LT: Design *new data science approaches exploring various team formations'* impact on learning outcomes.

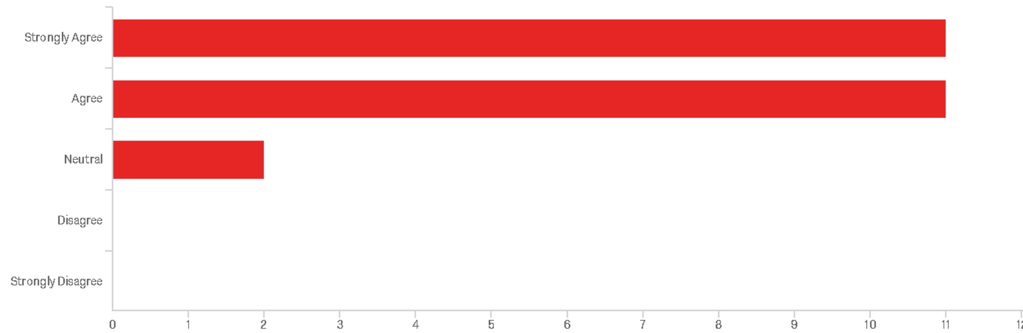
LT: Apply and extend *ML/AI technologies within DMTL* to: (a) longitudinally suggest (or automatically construct) team learning activities personalized to the learners at-hand, (b) hybridize DMTL with Intelligent Tutoring Systems (ITS) whereby ITS agents have co-instructor roles, and (c) adapt the XR environment to spontaneously insert virtual teammates at pivotal moments, e.g. triggered by wheel spinning / wrong path.

DMTL-Exist-Report-Format-1

DMTL-Exit-Survey-2019

May 21, 2019 1:50 PM EDT

I.1. - I. Workshop Format The workshop's schedule was appropriate:

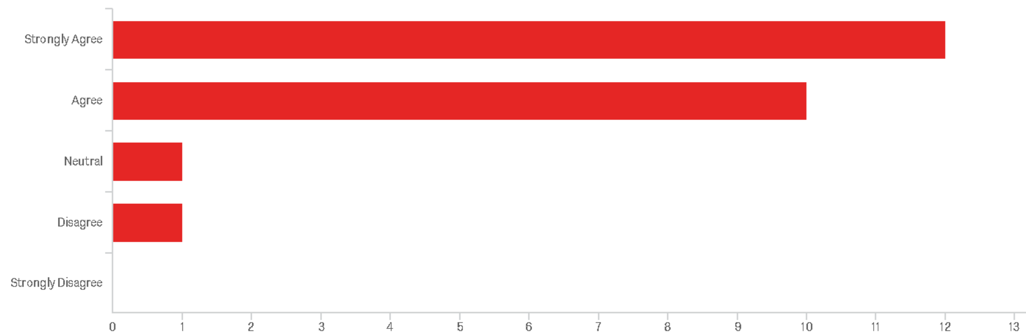


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I. Workshop Format The workshop's schedule was appropriate:	1.00	3.00	1.63	0.63	0.40	24

#	Field	Choice Count	
1	Strongly Agree	45.83%	11
2	Agree	45.83%	11
3	Neutral	8.33%	2
4	Disagree	0.00%	0
5	Strongly Disagree	0.00%	0
			24

Showing rows 1 - 6 of 6

I.2. - The activities offered helped to facilitate NSF's "Synthesis & Design Workshop" vision for participation and assimilation of ideas from the attendees:

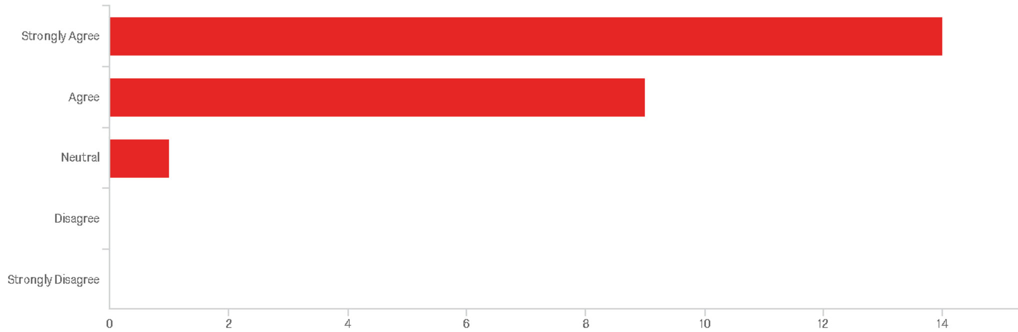


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	The activities offered helped to facilitate NSF's "Synthesis & Design Workshop" vision for participation and assimilation of ideas from the attendees:	1.00	4.00	1.63	0.75	0.57	24

#	Field	Choice	Count
1	Strongly Agree	50.00%	12
2	Agree	41.67%	10
3	Neutral	4.17%	1
4	Disagree	4.17%	1
5	Strongly Disagree	0.00%	0
			24

Showing rows 1 - 6 of 6

I.3. - The provision of invited speakers, panel discussions, and/or tours was worthwhile:

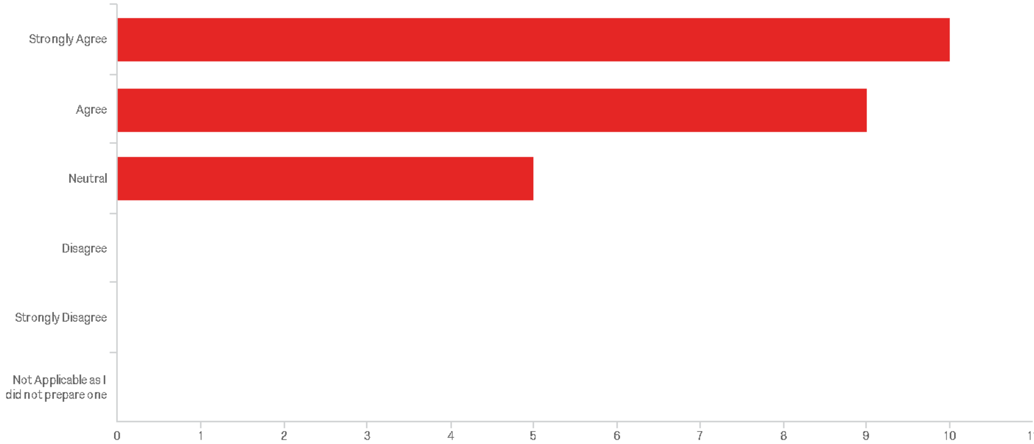


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	The provision of invited speakers, panel discussions, and/or tours was worthwhile:	1.00	3.00	1.46	0.58	0.33	24

#	Field		Choice Count
1	Strongly Agree	58.33%	14
2	Agree	37.50%	9
3	Neutral	4.17%	1
4	Disagree	0.00%	0
5	Strongly Disagree	0.00%	0
			24

Showing rows 1 - 6 of 6

I.4. - Preparation of a Position Abstract was useful to organize my own contributions to this workshop:

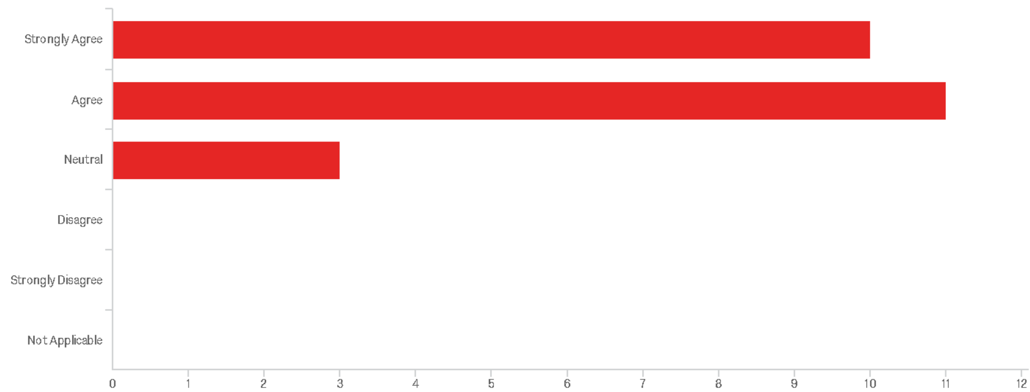


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Preparation of a Position Abstract was useful to organize my own contributions to this workshop:	1.00	3.00	1.79	0.76	0.58	24

#	Field		Choice Count
1	Strongly Agree	41.67%	10
2	Agree	37.50%	9
3	Neutral	20.83%	5
4	Disagree	0.00%	0
5	Strongly Disagree	0.00%	0
6	Not Applicable as I did not prepare one	0.00%	0
			24

Showing rows 1 - 7 of 7

I.5. - Organization of technical content into Tracks and Themes having Guiding Questions identified prior to conducting a Synthesis & Design Workshop is useful:

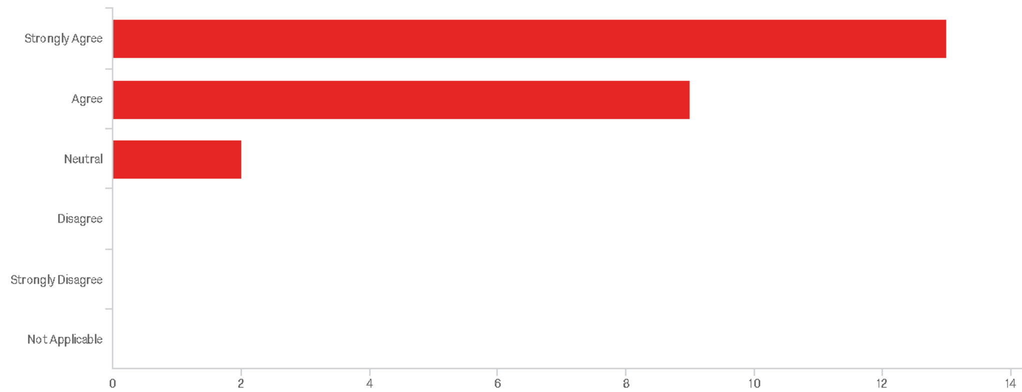


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Organization of technical content into Tracks and Themes having Guiding Questions identified prior to conducting a Synthesis & Design Workshop is useful:	1.00	3.00	1.71	0.68	0.46	24

#	Field		Choice Count
1	Strongly Agree	41.67%	10
2	Agree	45.83%	11
3	Neutral	12.50%	3
4	Disagree	0.00%	0
5	Strongly Disagree	0.00%	0
6	Not Applicable	0.00%	0
			24

Showing rows 1 - 7 of 7

I.6. - Use of technology (i.e. GoogleDocs, Swivl tracker, Web-posted resources) was beneficial versus conventional un-automated Synthesis & Design activities (i.e. roundtables, note-taking, paper-based materials):

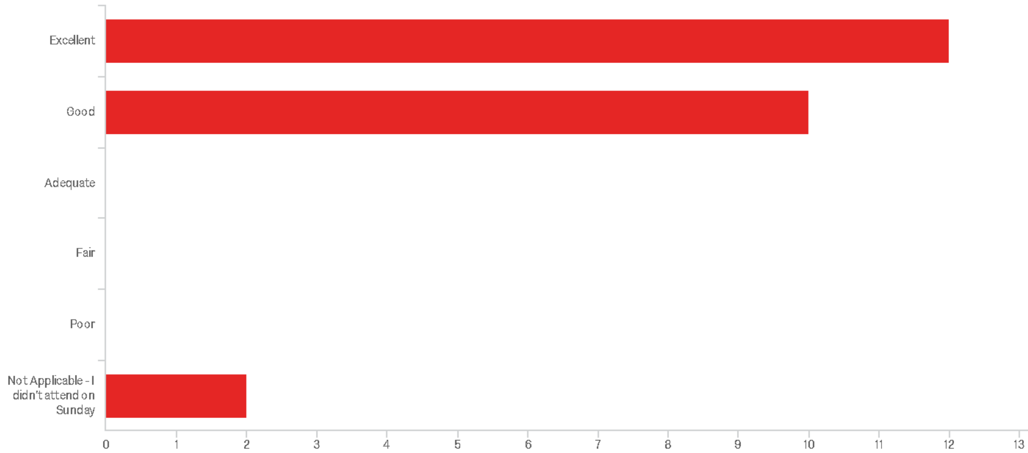


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Use of technology (i.e. GoogleDocs, Swivl tracker, Web-posted resources) was beneficial versus conventional un-automated Synthesis & Design activities (i.e. roundtables, note-taking, paper-based materials):	1.00	3.00	1.54	0.64	0.41	24

#	Field	Choice Count	
1	Strongly Agree	54.17%	13
2	Agree	37.50%	9
3	Neutral	8.33%	2
4	Disagree	0.00%	0
5	Strongly Disagree	0.00%	0
6	Not Applicable	0.00%	0
			24

Showing rows 1 - 7 of 7

II.1. - II. Workshop Delivery I would rate Sunday's reception as:

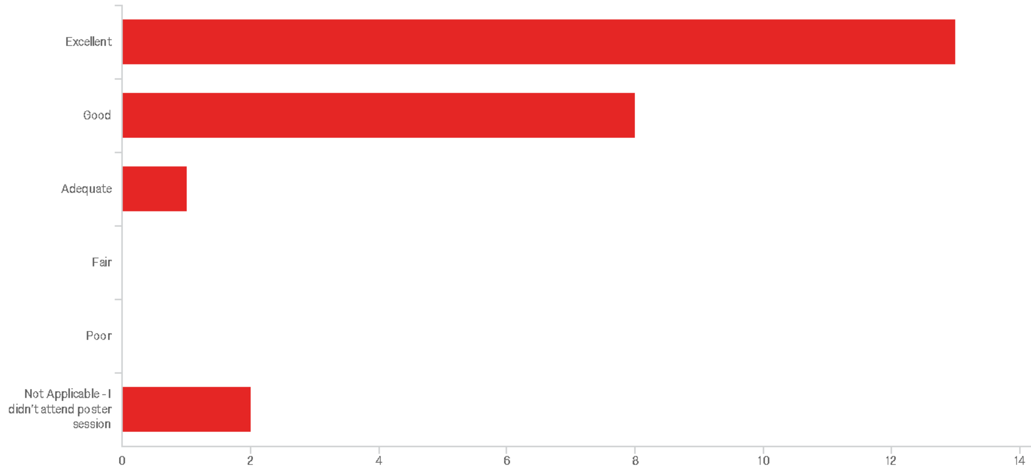


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	II. Workshop Delivery I would rate Sunday's reception as:	1.00	6.00	1.83	1.34	1.81	24

#	Field		Choice Count
1	Excellent	50.00%	12
2	Good	41.67%	10
3	Adequate	0.00%	0
4	Fair	0.00%	0
5	Poor	0.00%	0
6	Not Applicable - I didn't attend on Sunday	8.33%	2
			24

Showing rows 1 - 7 of 7

II.2. - The poster session was worthwhile:

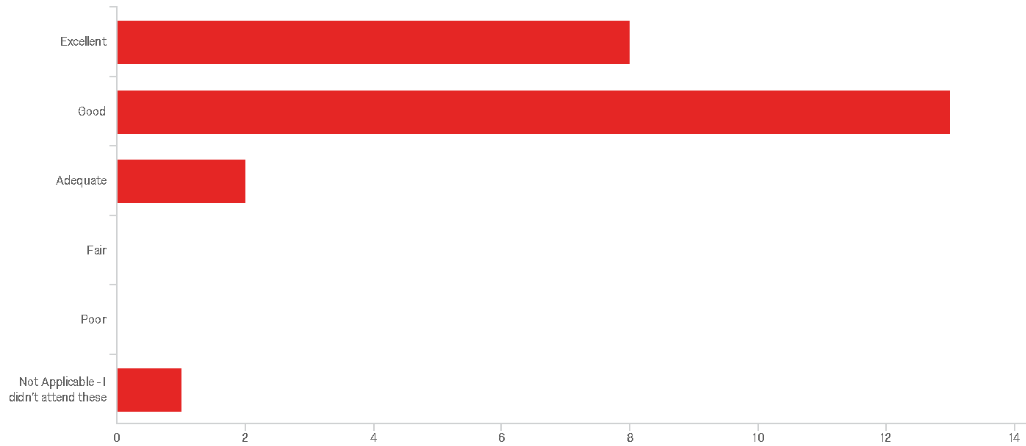


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	The poster session was worthwhile:	1.00	6.00	1.83	1.37	1.89	24

#	Field	Choice Count	
1	Excellent	54.17%	13
2	Good	33.33%	8
3	Adequate	4.17%	1
4	Fair	0.00%	0
5	Poor	0.00%	0
6	Not Applicable - I didn't attend poster session	8.33%	2
			24

Showing rows 1 - 7 of 7

II.3. - The overview presentations and status recaps were beneficial:

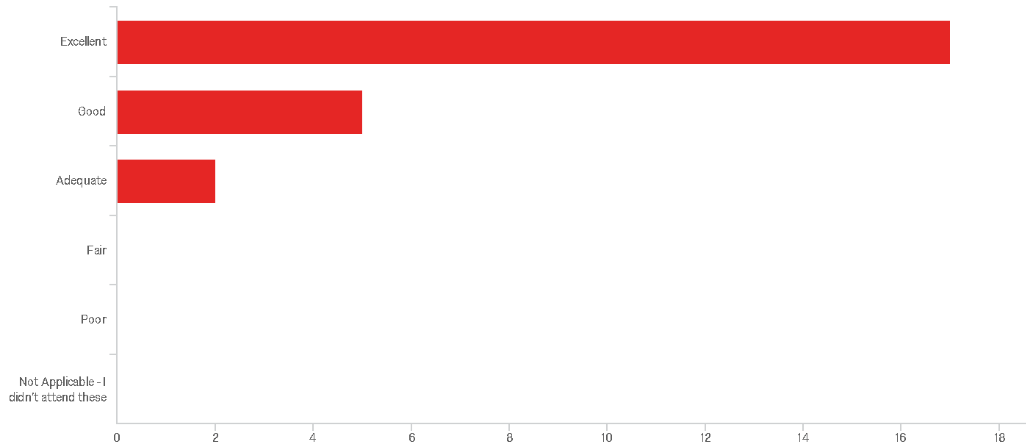


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	The overview presentations and status recaps were beneficial:	1.00	6.00	1.92	1.04	1.08	24

#	Field		Choice Count
1	Excellent	33.33%	8
2	Good	54.17%	13
3	Adequate	8.33%	2
4	Fair	0.00%	0
5	Poor	0.00%	0
6	Not Applicable - I didn't attend these	4.17%	1
			24

Showing rows 1 - 7 of 7

II.4. - The invited talks were beneficial:

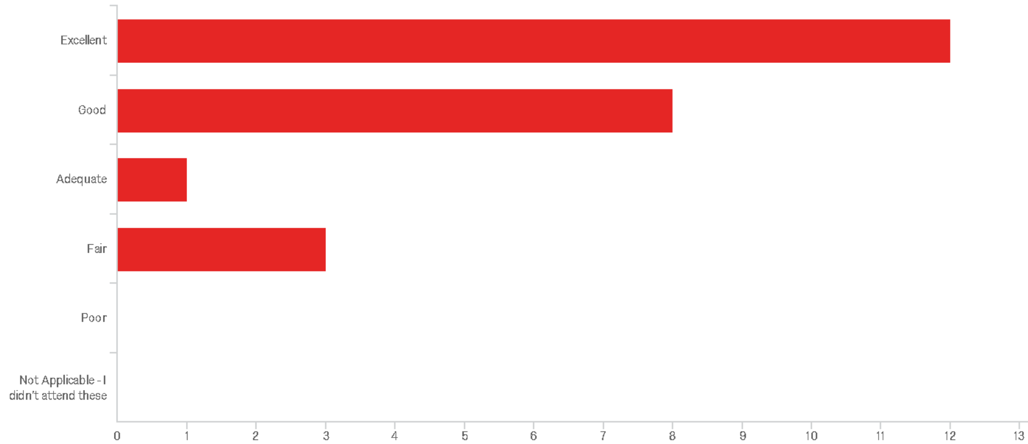


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	The invited talks were beneficial:	1.00	3.00	1.38	0.63	0.40	24

#	Field		Choice Count
1	Excellent	70.83%	17
2	Good	20.83%	5
3	Adequate	8.33%	2
4	Fair	0.00%	0
5	Poor	0.00%	0
6	Not Applicable - I didn't attend these	0.00%	0
			24

Showing rows 1 - 7 of 7

II.5. - The breakout sessions were effective:

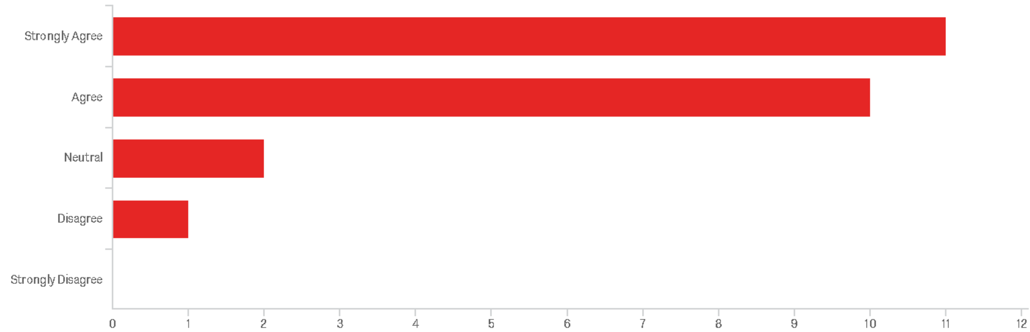


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	The breakout sessions were effective:	1.00	4.00	1.79	1.00	1.00	24

#	Field		Choice Count
1	Excellent	50.00%	12
2	Good	33.33%	8
3	Adequate	4.17%	1
4	Fair	12.50%	3
5	Poor	0.00%	0
6	Not Applicable - I didn't attend these	0.00%	0
			24

Showing rows 1 - 7 of 7

II.6. - The meeting achieved a reasonably-efficient flow:

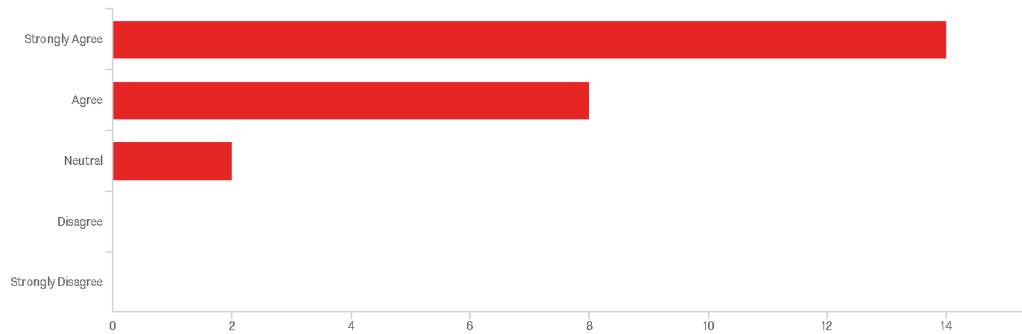


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	The meeting achieved a reasonably-efficient flow:	1.00	4.00	1.71	0.79	0.62	24

#	Field	Choice Count	
1	Strongly Agree	45.83%	11
2	Agree	41.67%	10
3	Neutral	8.33%	2
4	Disagree	4.17%	1
5	Strongly Disagree	0.00%	0
			24

Showing rows 1 - 6 of 6

III.1. - III. Workshop Support The website displayed useful information in a useable format:

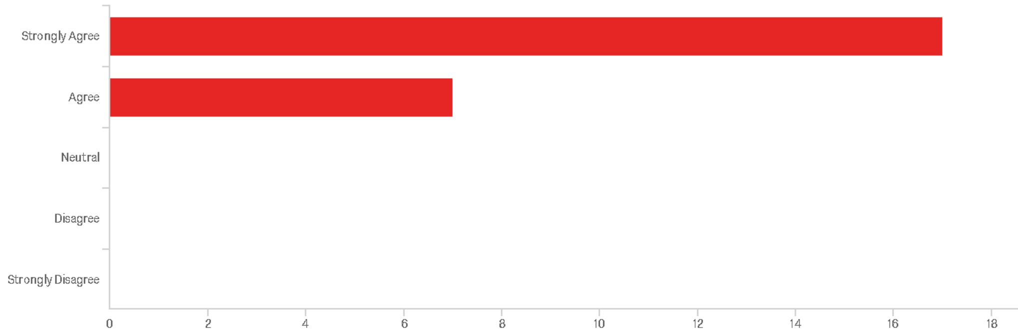


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	III. Workshop Support The website displayed useful information in a useable format:	1.00	3.00	1.50	0.65	0.42	24

#	Field	Choice Count	
1	Strongly Agree	58.33%	14
2	Agree	33.33%	8
3	Neutral	8.33%	2
4	Disagree	0.00%	0
5	Strongly Disagree	0.00%	0
			24

Showing rows 1 - 6 of 6

III.2. - The pre-conference logistics support was sufficient:

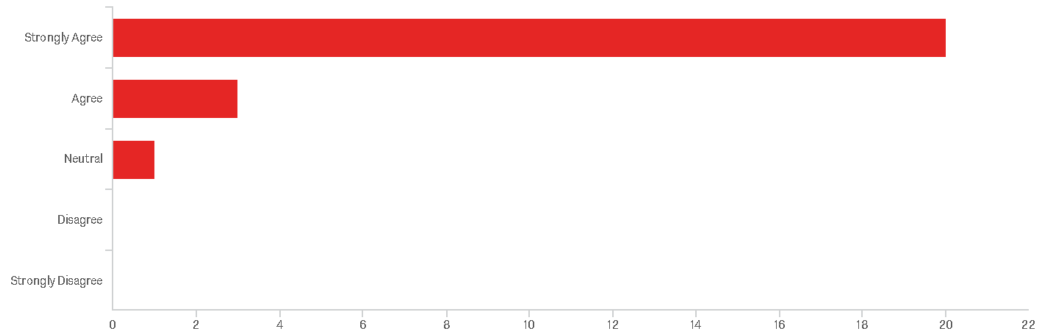


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	The pre-conference logistics support was sufficient:	1.00	2.00	1.29	0.45	0.21	24

#	Field	Choice Count	
1	Strongly Agree	70.83%	17
2	Agree	29.17%	7
3	Neutral	0.00%	0
4	Disagree	0.00%	0
5	Strongly Disagree	0.00%	0
			24

Showing rows 1 - 6 of 6

III.3. - The meeting center facilities were adequate and appropriate:

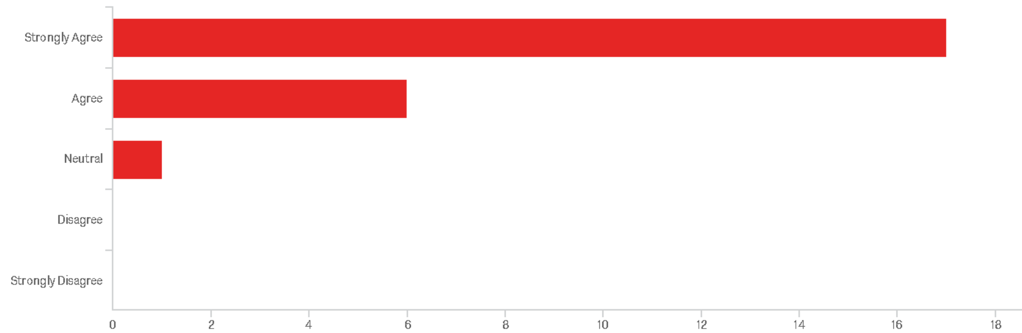


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	The meeting center facilities were adequate and appropriate:	1.00	3.00	1.21	0.50	0.25	24

#	Field	Choice Count	
1	Strongly Agree	83.33%	20
2	Agree	12.50%	3
3	Neutral	4.17%	1
4	Disagree	0.00%	0
5	Strongly Disagree	0.00%	0
			24

Showing rows 1 - 6 of 6

III.4. - The meeting's catering and refreshments were satisfactory:

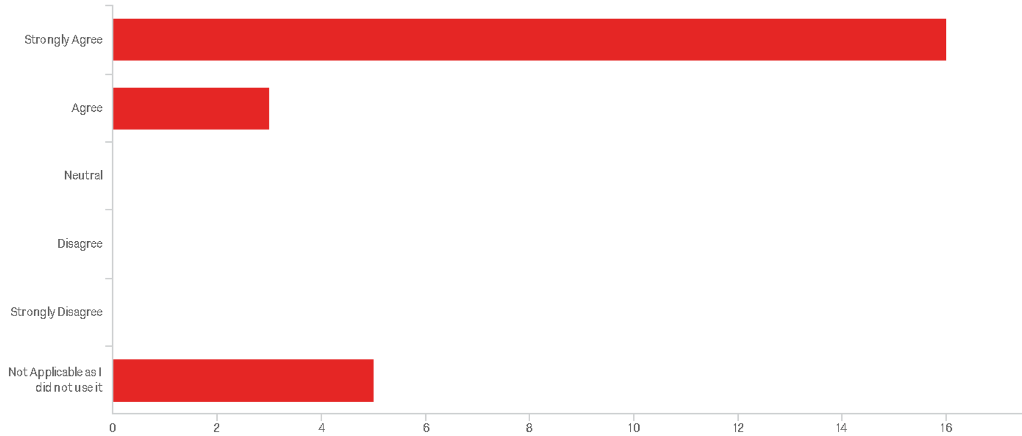


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	The meeting's catering and refreshments were satisfactory:	1.00	3.00	1.33	0.55	0.31	24

#	Field	Choice Count	
1	Strongly Agree	70.83%	17
2	Agree	25.00%	6
3	Neutral	4.17%	1
4	Disagree	0.00%	0
5	Strongly Disagree	0.00%	0
			24

Showing rows 1 - 6 of 6

III.5. - The hotel shuttle service was adequate:

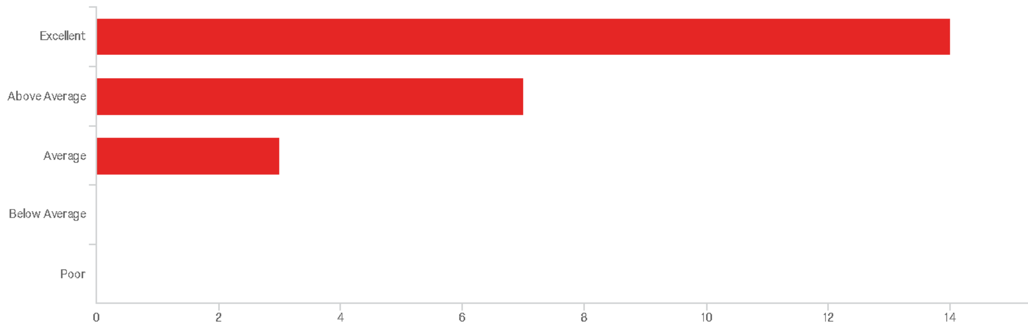


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	The hotel shuttle service was adequate:	1.00	6.00	2.17	1.99	3.97	24

#	Field	Choice Count	
1	Strongly Agree	66.67%	16
2	Agree	12.50%	3
3	Neutral	0.00%	0
4	Disagree	0.00%	0
5	Strongly Disagree	0.00%	0
6	Not Applicable as I did not use it	20.83%	5
			24

Showing rows 1 - 7 of 7

IV.1. - IV. Workshop Impact Please share your overall impression of this workshop:

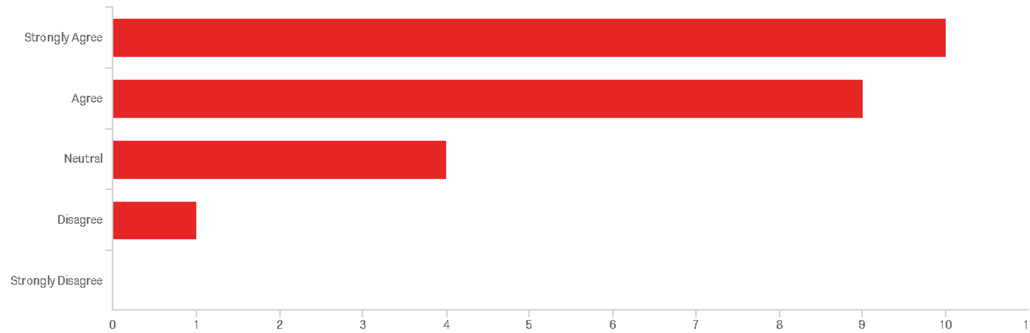


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	IV. Workshop Impact Please share your overall impression of this workshop:	1.00	3.00	1.54	0.71	0.50	24

#	Field	Choice Count	
1	Excellent	58.33%	14
2	Above Average	29.17%	7
3	Average	12.50%	3
4	Below Average	0.00%	0
5	Poor	0.00%	0
			24

Showing rows 1 - 6 of 6

IV.2. - There were technical aspects covered that I will use to advance my own research:

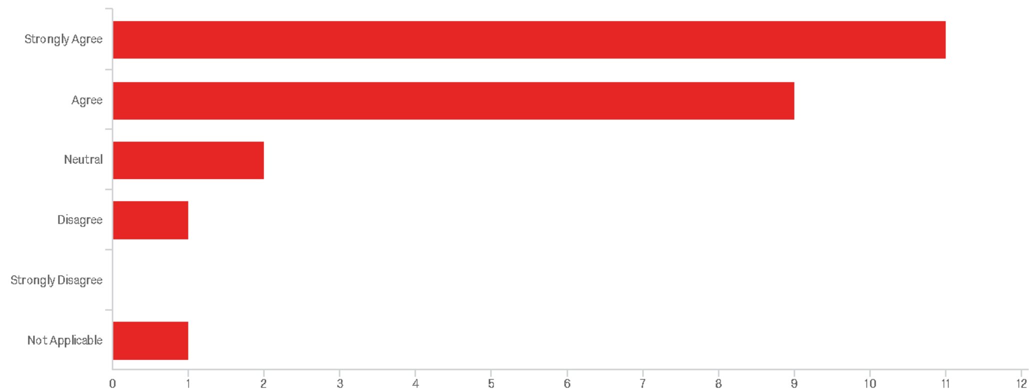


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	There were technical aspects covered that I will use to advance my own research:	1.00	4.00	1.83	0.85	0.72	24

#	Field	Choice Count	
1	Strongly Agree	41.67%	10
2	Agree	37.50%	9
3	Neutral	16.67%	4
4	Disagree	4.17%	1
5	Strongly Disagree	0.00%	0
			24

Showing rows 1 - 6 of 6

IV.3. - Participating in this workshop has further motivated me to consider technology-enhanced team learning within my own teaching activities:

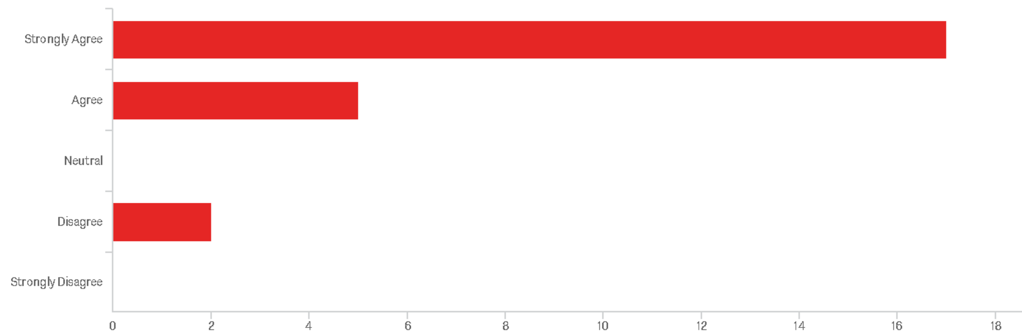


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Participating in this workshop has further motivated me to consider technology-enhanced team learning within my own teaching activities:	1.00	6.00	1.88	1.17	1.36	24

#	Field		Choice Count
1	Strongly Agree	45.83%	11
2	Agree	37.50%	9
3	Neutral	8.33%	2
4	Disagree	4.17%	1
5	Strongly Disagree	0.00%	0
6	Not Applicable	4.17%	1
			24

Showing rows 1 - 7 of 7

IV.4. - I consider participation in this workshop as being beneficial to my broader professional development:

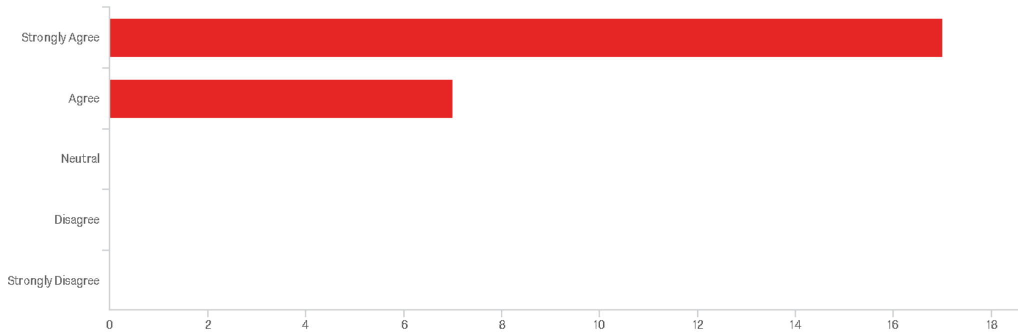


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I consider participation in this workshop as being beneficial to my broader professional development:	1.00	4.00	1.46	0.87	0.75	24

#	Field	Choice Count	
1	Strongly Agree	70.83%	17
2	Agree	20.83%	5
3	Neutral	0.00%	0
4	Disagree	8.33%	2
5	Strongly Disagree	0.00%	0
			24

Showing rows 1 - 6 of 6

IV.5. - I would like if NSF offered additional Synthesis & Design Workshops:

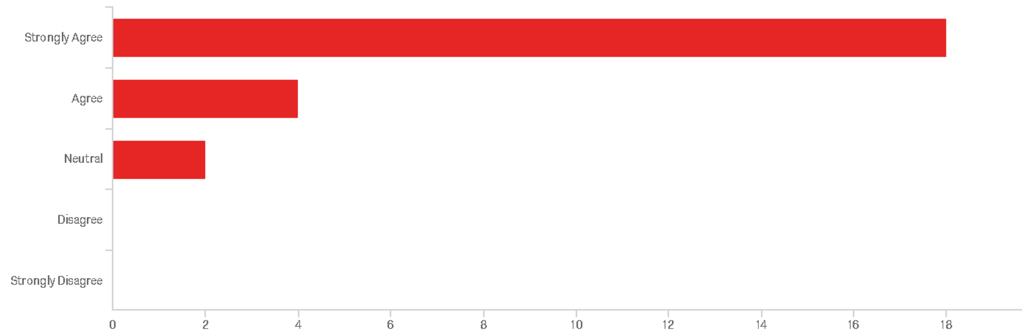


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I would like if NSF offered additional Synthesis & Design Workshops:	1.00	2.00	1.29	0.45	0.21	24

#	Field	Choice Count	
1	Strongly Agree	70.83%	17
2	Agree	29.17%	7
3	Neutral	0.00%	0
4	Disagree	0.00%	0
5	Strongly Disagree	0.00%	0
			24

Showing rows 1 - 6 of 6

IV.6. - I would attend other workshops offered by these facilitators:



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I would attend other workshops offered by these facilitators:	1.00	3.00	1.33	0.62	0.39	24

#	Field	Choice Count	
1	Strongly Agree	75.00%	18
2	Agree	16.67%	4
3	Neutral	8.33%	2
4	Disagree	0.00%	0
5	Strongly Disagree	0.00%	0
			24

Showing rows 1 - 6 of 6

V.1. - V. Free Response Overall, which aspect did you like best or find most useful about the workshop?

V. Free Response Overall, which aspect did you like best or find most usefu...
collaboration and also networking
Networking with folks.
Discussions during breakout sessions
The keynote/invited speakers were the most impressive and beneficial aspects of the entire workshop.
Breakout sessions
meeting colleagues and discussing efforts underway
The conversations were just terrific -- great folks! The Keynotes gave great fodder for the conversations. Sometimes - rarely - all the factors at a workshop come together. THIS IS ONE where EVERYTHING good came together. It was a GREAT event.
I enjoyed Chris Dede's keynote. The breakout sessions were a good idea as well.
Keynote talks, interactions with colleagues
communicating within the track
The invited talks were the best aspects of the workshop. They gave wonderful, relevant talks that were an inspiration. Many of the talks were referenced throughout the workshop.
Connecting with other scholars on a joint topic, and thinking about the future of the field.
Good mix of people and unique format
Finding out what others' needs and current uses were, mostly beyond my immediate experiences
The workshop was efficient and effective and I felt like everyone contributed.
The networking and collaborative discussion during the tracks was an excellent example of collaborative professional development and collegiality.
Very intelligent and skilled groups of participants, leaders, and keynotes
keynotes were terrific, all of them
I appreciated the ability to have more focused discussions with smaller groups; it helped with idea generation. Also the ability to revisit and refine.

V.2. - Which strategies/techniques utilized to conduct breakout sessions did you find to be the most useful?

Which strategies/techniques utilized to conduct breakout sessions did you f...
Knowing other people's perspectives
Freedom to go to different sessions.
Questions and answers with flexibility for anyone to present an idea
The use of the Google Docs was helpful in theory, although I am uncertain to what extent my track used this and its time well
Conversation... conversation... the old way... yes, we used the google docs for recording, but the issues came out during the old-fashioned conversation.
I liked the use of a running Google Doc.
Effective brainstorming with effective facilitators.
practicing dmtl
Given the large size, breaking the sessions into smaller groups sometimes was more productive. There was also the issue where the topics would overlap too much, and things said were repetitive.
Using a Google doc with themes and relevant questions beforehand helped to spark discussion.
Small group size allowed for trust and open sharing.
Breaking into smaller sub-groups. Different approaches. Working individually first, then followed by a team exercise.
Ability to have their flow be adaptive was great, break out in to smaller groups from the larger group.
Google docs, facilitators making sure we stayed on track.
The use of Google Doc was effective for collaboration.
20 minute discussions and goal-oriented, deadline oriented sessions.
I think the sessions were too long....looked like we were ready to move to the next question after a mere 30 minutes, not an hour.
see above

V.3. - If you were to tell someone about this workshop, what would you say?

If you were to tell someone about this workshop, what would you say?
Excellent
Great people and great facilitation.
We collaborated on digital mediated learning spaces and began a framework for a white paper on the subject.
I was excited to attend the workshop so I could contribute and learn. I wonder if my track was anomalous in that it did not move through the themes in depth nor efficiently. If so, I regret not visiting other tracks. If not, then I think other mechanisms need to be instituted to better organize contributions and workflow.
Great conference
too much focus on technology development and tool little emphasis on developing human reasoning
I would say there were a lot of researchers from different disciplines/different theoretical perspectives, and I enjoy hearing different perspectives.
It was awesome and valuable!
"We collaborated and cooperated to discover more about each other and our work in DMTL."
Well organized and thoughtful content.
Very thoughtful group engaged in some important discussion.
Lots of different experiences and needs brought the larger picture into focus
You'll get a lot done and learn a lot.
The PI's did a wonderful job of designing and facilitating this workshop. It was an extremely valuable experience.
Excellent place to learn and advance your knowledge about teamwork
it was worth, great colleagues, great ideas, excellent facilities
It depends on the audience ;-) It was a focused meeting to develop visions for future development of DMTL.

V.4. - Do you have any suggestions and/or ideas to improve future workshops?

Do you have any suggestions and/or ideas to improve future workshops?
No. Everything is perfect.
More large group check ins to motivate and inspire each group.
Having some "prompt questions" for the breakout sessions might get discussions going sooner.
See above.
use speakers to spark discussion - shorter presentations and more time discussing issues
The breakout sessions were a good idea, however since they were concurrent, it was unlikely that people got a feel for all the tracks. Maybe instead of doing the tracks for both days, do two tracks per day so people can attend more?
I think between sessions, we needed to have a few minutes coffee breaks, which will help refresh our minds, especially when things were getting more intensive on the second day. It was hard to be concentrated again without needed breaks.
more breaks in between session smaller groups like 2 track ones or 2 track twos
A discussion of shared taxonomy of terms. When bringing folks from different disciplines together there are often different ideas of what terms or concepts mean.
If a track is large, break it up into smaller groups. The facilitator should keep the topic of the conversation close to the themes and questions. It would have been beneficial for participants to sit in a circle and to also have easy access to outlets.
Good work on adjusting the schedule for Day 2.
I would add some more high level guidance on the objective of what we (or NSF) is trying to achieve. Maybe we should approach this like a collaborative problem solving exercise and consider some of these techniques.
DECOMPRESSION TIME; no speakers during lunch.
slightly more break time
A little down time would have been nice to allow some of those brain cells to recover. The lunch presentations were interesting but I would have preferred to socialize
shorten break out session and mix participants a little more
A mechanism for cross-pollinating groups would be useful.