Driving Interdisciplinary Collaboration through Adapted Conjecture Mapping: A Case Study with the PECAS Mediator

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Executive Summary

In this report, we demonstrate how an interdisciplinary team of computer science and learning sciences researchers utilize an adapted conjecture mapping tool during a collaborative problem-solving session. The session is documented through an edited "Dialogue" format, which captures the process of conjecture map construction and subsequent reflection. We find that creating the conjecture map collaboratively surfaces a key tension: while learning sciences theory often highlights the nuanced and complex relational nature of learning, even the most cutting-edge computing techniques struggle to discern these nuances. Articulating this tension proved to be highly generative, enabling the researchers to discuss how considering impacted community members as a critical "part of the solution" may lead to a socio-technical tool which supports desired learning outcomes, despite limitations in learning theory and technical capability. Ultimately, the process of developing the conjecture map directed researchers toward a precise discussion about *how* they would need to engage impacted community members in a co-design process.

Introduction

With the increasing pace of computer science innovation in fields like artificial intelligence (AI) (Zhang et al., 2021), funding agencies have begun to emphasize mutual collaborations where computer scientists and learning scientists are equally in research lead positions. For example, in the United States, the National Science Foundation has funded three $20 million AI Institutes (NSF, 2021), each which must foster collaboration between foundational AI researchers and use-inspired learning scientists. Despite this mounting interest, interdisciplinary collaboration is rife with challenges as researchers struggle to get on the same page about key issues about technical feasibility, ideology, aligning technical goals with learning goals, understanding the complexity of real learning environments, among others. Recent work by Chang and Roschelle (2022) has sought to adapt conjecture maps, a commonly used tool within the practice of design-based research (Design-Based Research Collective, 2003), to better support learning scientists and computer scientists in this endeavor. In this report, we describe a case study involving the Productive Engagement through Collaborative Action and Sociology (PECAS) Mediator, documenting how an adapted conjecture map can serve as a powerful collaborative artifact which connects theories of learning and existing computer science techniques and through this, opens up interfaces of interdisciplinary collaboration.

The PECAS Mediator, led by principal investigators Dr. Alejandra Magana, Dr. Bedrich Benes, Dr. Dominic Kao, and Dr. Jennifer Richardson, is a remote instruction tool which assists instructors in identifying unproductive collaborations. Using AI-based techniques, the PECAS Mediator (*Productive Engagement through Collaborative Action and Sociology (PECAS) Mediator – CIRCLS*, 2022) automatically identifies moments of unproductive collaboration, notifies an instructor, and provides hints to the instructor about how they may effectively intervene. While the project is still in the early phases, the researchers have taken a proactive approach towards considering both the potential intended and unintended outcomes of their tool in remote classrooms. We found that this act of anticipation (Stilgoe et al., 2013), a key component of "responsible innovation," opened the door to a variety of fascinating discussions which may come to shape the development of the tool from an early stage.

This report will start off by providing background on conjecture maps and adaptations we made to it for the purposes of this discussion. Next, we will describe the PECAS Mediator in greater detail and document how the PECAS team initially approached creating an adapted conjecture map. We then describe, in the form of an edited dialogue, how the PECAS Mediator team developed an adapted conjecture map (Chang & Roschelle, 2022). We conclude by sharing several key reflections about the edited dialogue.

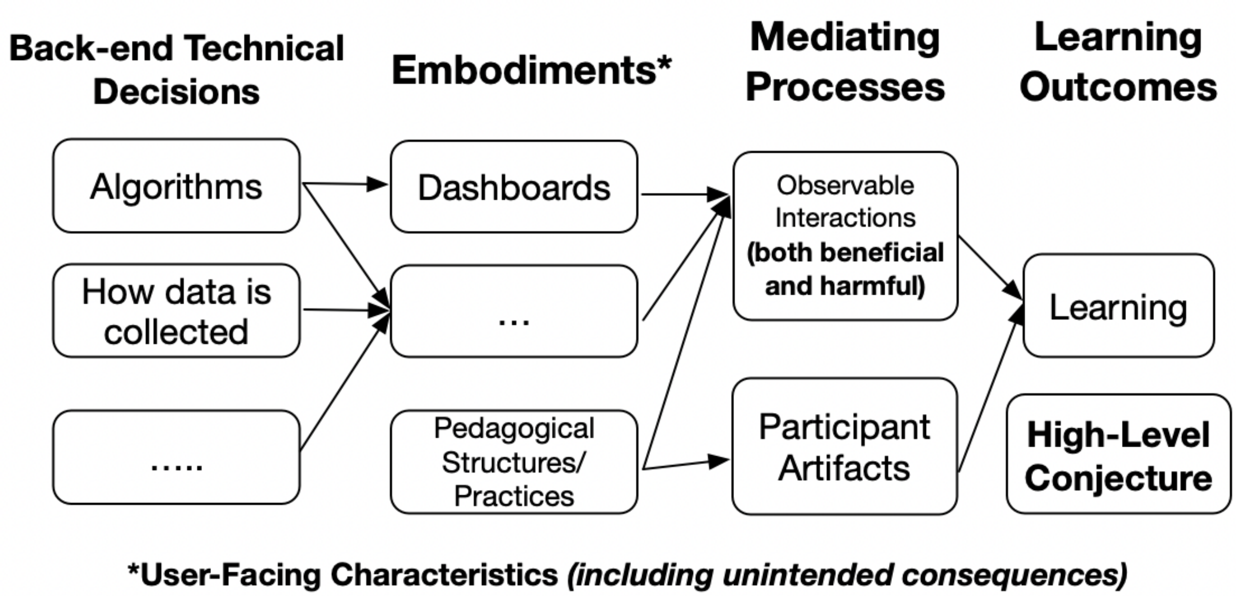
Background

Conjecture maps, as initially proposed by Sandoval (2014), is a tool that supports researchers in systematically co-develop learning sciences theory and design. Rooted in a tradition of design-based research (DBR), conjecture maps allow researchers to make conjectures or inferences about the relationship between embodiments (e.g., technological designs, pedagogical structures, and discursive practices), how those embodiments are taken up by impacted communities, and the desired learning outcomes of the technical intervention.

Chang and Roschelle (2022), through a series of interviews with computer scientists, identified two key limitations in the structure of Sandoval's conjecture map. First, a significant amount of research done by computer scientists do not directly interface with the user; they are more typically "back-end" challenges with uncertain downstream implications (e.g., AI models, selection of data used to train the AI models, etc.). Second, conjecture maps traditionally tend to focus on the positive outcomes of a design. Because of the uncertain downstream effects of technical decisions, technology under development must also explicitly consider how the technology may bear unintended consequences that actually inhibit desired learning outcomes of a learning support. Taken together, Chang and Roschelle created an adapted conjecture mapping tool, as shown below in Figure 1.

Figure 1

An Adapted Conjecture Map Framework for Learning Scientists and Computer Scientists



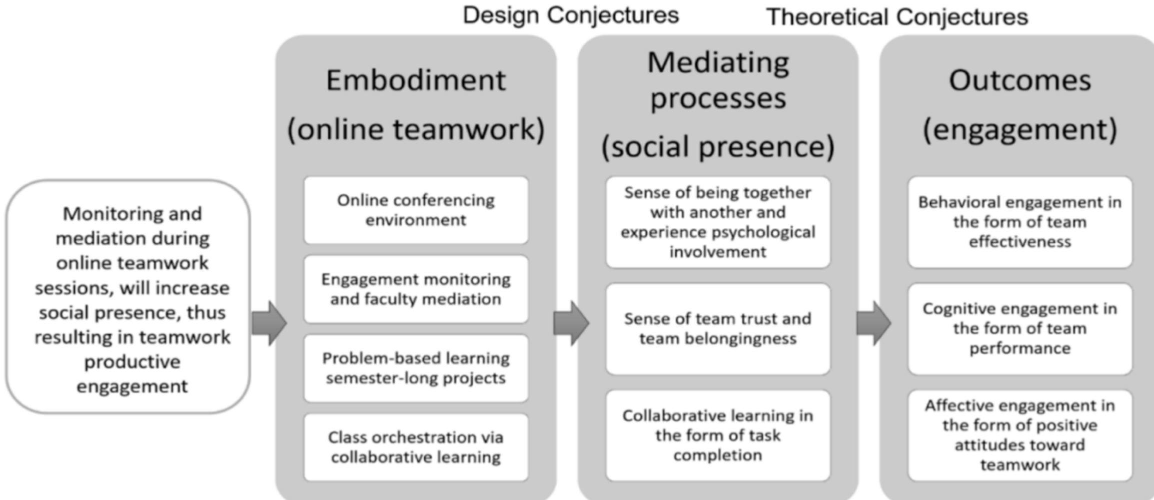
The adapted conjecture map makes a key distinction between back-end technical decisions and Embodied front-end decisions (second column in Figure 1). More precisely, front-end decisions are embodied features that users will directly interact with (e.g., dashboard), whereas back-end technical decisions are likely to be more behind the scenes (e.g., data infrastructure set-up, what is being used for the training data of an AI model, etc.) Arrows between the back-end technical decision and the embodiments leads to computer science researchers grappling with how users may interface with technical decisions that might previously have been considered either ethically or pedagogically neutral. Past work such as Chang and Philip (2022) have shown that technical decisions like data privacy (e.g., who data is shared with) has significant pedagogical implications on relationships and learning. The adapted conjecture map also encourages designers to consider both beneficial and harmful consequences of the technology, which manifest in the framework either as an embodiment or a mediating process. An example of this might be the effects of algorithmic bias; e.g., which groups may be disproportionately harmed by a particular technical design?

PECAS Mediator Background

The PECAS mediator is a recently funded project that brought together a diverse team of learning scientists and computer scientists in the creation of a new tool for online teamwork. As shown in Figure 2, the PECAS team theorized that “monitoring and mediation during online teamwork sessions will increase social presence, thus resulting in teamwork productive engagement.” The work seeks to bring the power of AI to bear on the challenge of supporting instructors in knowing which virtual teams needed support, and what kinds of support would be most helpful.

Dr. Alejandra Magana, a learning scientist experienced in the art of creating conjecture maps, iterated through several versions before arriving at the conjecture map shown in Figure 2. During this process, Dr. Magana took the lead in creating the conjecture maps, and once completed, shared them with the computer scientists on the PECAS Mediator team. In our discussions, the computer scientists indicated that conjecture maps were a useful reference, but otherwise it was difficult to draw the connections between the conjecture map and their own challenges in developing the algorithmic techniques necessary to make the PECAS Mediator a reality. Our next section details how the conjecture map revised tool in Figure 1 eventually translated to an adapted conjecture map.

Figure 2
Conjecture Map for the PECAS Mediator



Creating an Adapted Conjecture Map Together: A Dialogue

In this section, we present an edited *dialogue* that was held around developing an adapted conjecture map for the PECAS mediator project. While the dialogue is slightly edited for publication purposes, it stays true to the logical progression of the discussion and accurately attributes ideas.

The participants of the dialogue are as follows:

- Dr. Michael Alan Chang (Digital Promise, CIRCLS staff, UC Berkeley)
- Dr. Judi Fusco (Digital Promise, CIRCLS co-PI)
- Dr. Alejandra Magana (Purdue, PECAS Mediator Team)
- Dr. Bedrich Benes (Purdue University, PECAS Mediator Team)
- Dr. Dominic Kao (Purdue University, PECAS Mediator Team)

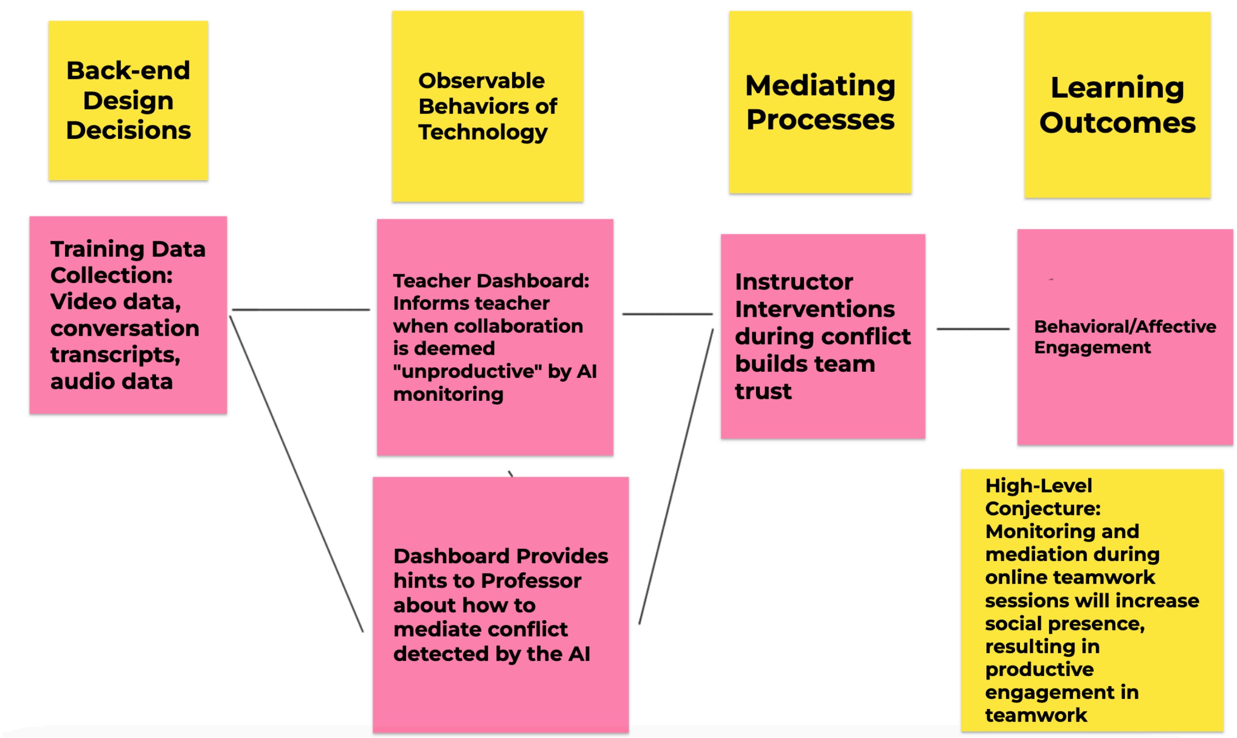
While Dr. Magana was previously familiar with conjecture maps, the facilitators initiated the discussion by explaining conjecture maps to Dr. Benes and Dr. Kao. Following this, the facilitators shared a Jamboard template with an empty adapted conjecture map, from which the interdisciplinary PECAS Mediator team worked together to create the conjecture map. We show how each contribution from a team member shaped the adapted conjecture map; new additions to the adapted conjecture map are shown as pink tabs, while previous additions are shown as green tabs. Yellow tabs represent the template categories for the conjecture map. The dialogue occurred over a one-hour segment.

Alejandra Magana: I definitely see the distinction between this adapted conjecture map and the traditional conjecture map by Sandoval. One key functionality of our work is monitoring unproductive behavior. Towards this, at a high level we are looking for three specific kinds of unproductive teamwork work: inactivity, conflict, or one person overpowering the whole conversation. In terms of data, we were considering emotion recognition, considering text data, audio data, and video data fitting into the dashboard. Moreover, since the instructor is not an expert, for example, in conflict resolution, our tool should give some hints to the professor about how to mediate conflict.

At this point, the participants updated the conjecture map template with the pink notes in Figure 3.

Figure 3

Conjecture Map Template as initially filled out based on Dr. Magana's initial description of the PECAS Mediator.



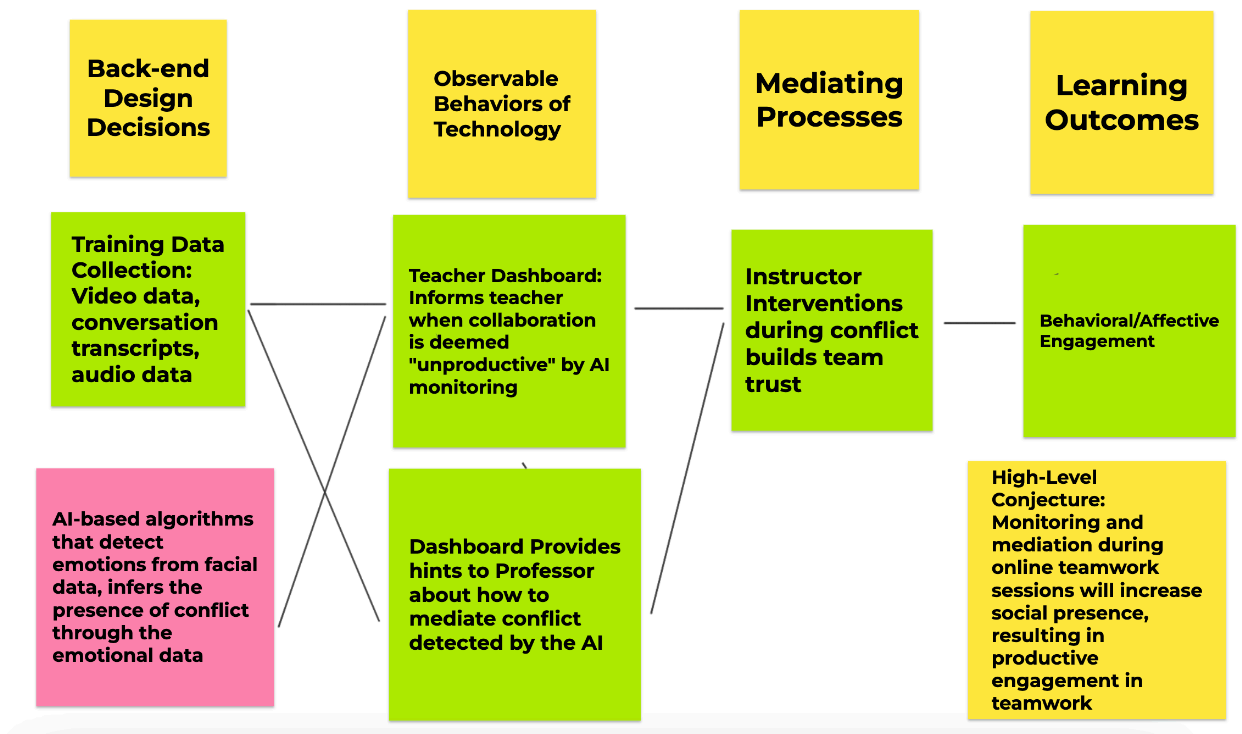
Note. Updates to the conjecture map are marked in pink.

Bedrich Benes: We will create algorithms that will detect the emotional state of each participant, without storing any personal or identifiable data. As you are talking on the conferencing system, the AI tracks whether people are positive or negative, or being active or non-active, and also then infer whether some kind of behavior is problematic or not. There are multiple steps: first is detection, second is mediation (mediator who is a human being), so this is the overall idea.

Based on Dr. Benes' comments, the conjecture map was updated to include details about the AI model, which are shown in pink in Figure 4.

Figure 4

Updated Conjecture Map that provides more detail about the AI model underlying the Teacher dashboard, as described by Dr. Benes



Note. Updates to the conjecture map are marked in pink.

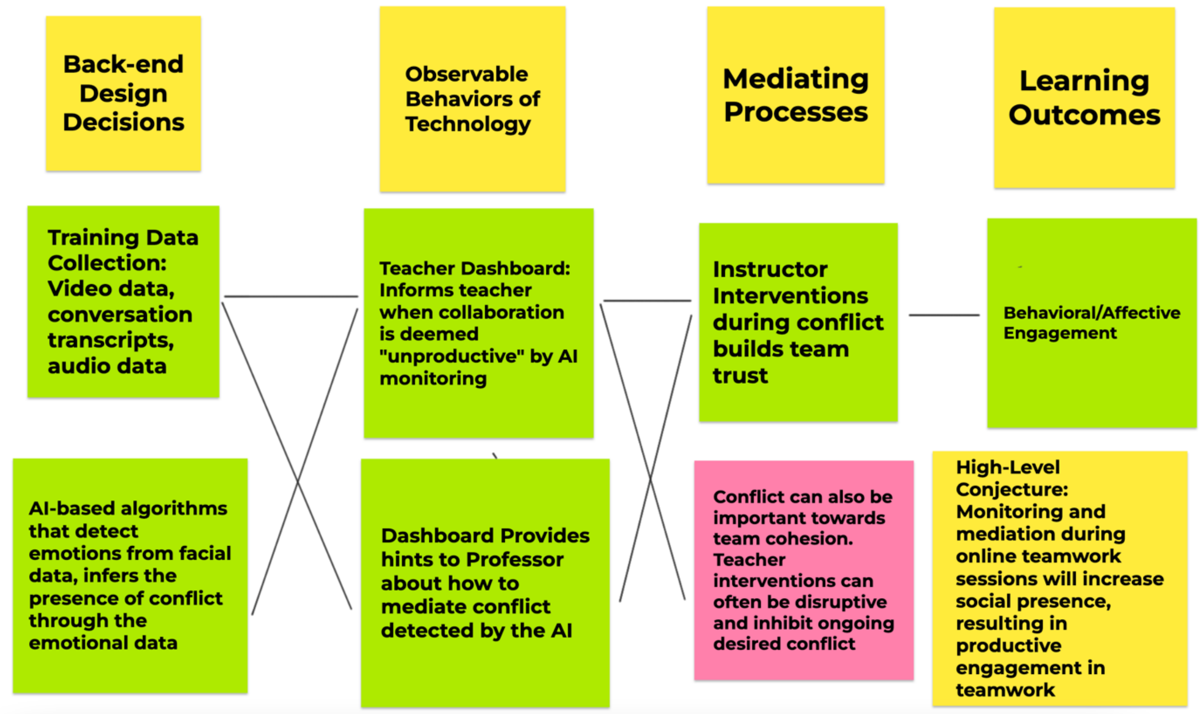
Michael Chang: This fills out part of our conjecture map very well. Thinking specifically about unintended consequences, is there anything you all are worried about? Especially from Alejandra's side, is there something about the instructor dashboard which may misdirect the instructor? How do we connect that back to the technical backend decisions being considered by Dominic and Bedrich?

Alejandra Magana: One thing that I would be curious to dig into more is that not all conflict is bad. If we look at the literature on stages of team formation, conflict is needed to reach team cohesion (De Dreu, 1997; Putnam, 1994). We might have started thinking that conflict is a negative thing, but it can be a positive thing. This is very consequential as our work is designed to help instructors decide when to intervene; when I lead a course, every team gets a virtual visit. Sometimes I interrupt a good discussion, which stops the flow of their team building and working. Ultimately, I worry about the implications of making a mistake in the AI's detection!

This comment – which can be considered an unintended consequence of the learning design – by Dr. Magana eventually led to yet another update to the conjecture map, shown in Figure 5.

Figure 5

Updated Conjecture Map that now includes Dr. Magana's concerns about the role of conflict in team-building



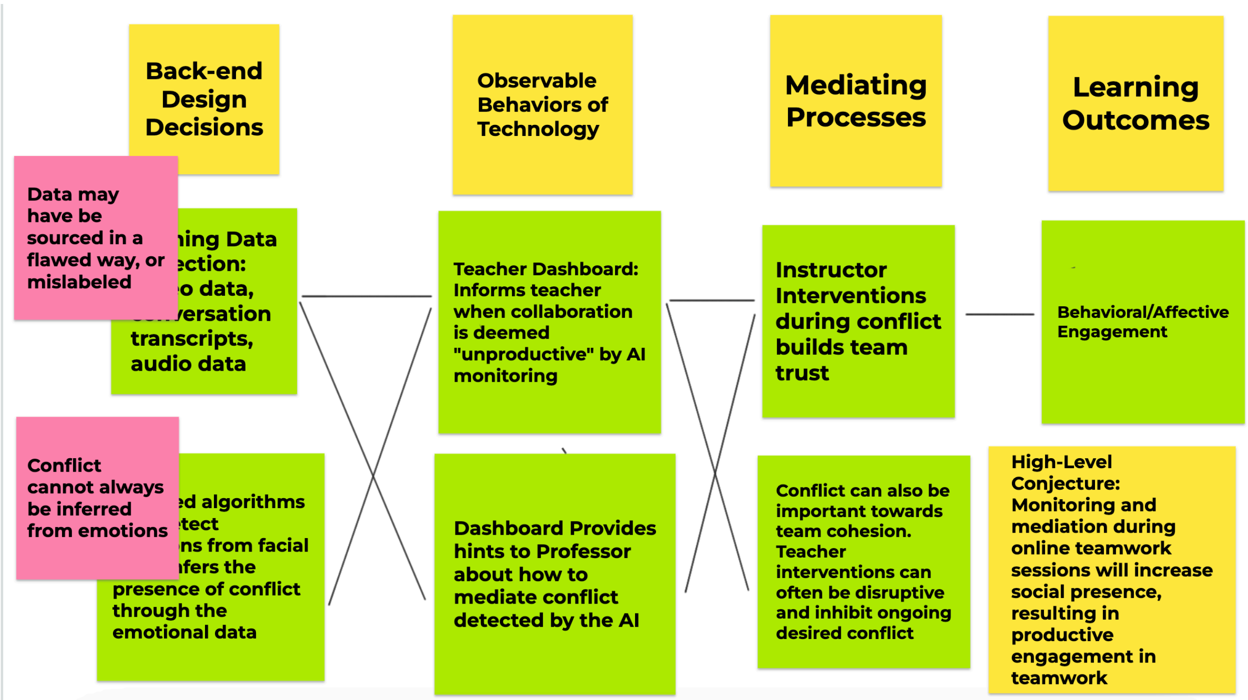
Note. Updates to the conjecture map are marked in pink.

Bredrich Benes and Dominic Kao: At the algorithmic level, things can go downhill at different levels. First, emotional recognition can have false positives and false negatives. Secondly, there is an underlying idea that emotion is connected to conflict or other unproductive behavior. We intuitively assume that it is, but it may not be. Classifiers themselves are imperfect, the second thing is that for the data we classify, the conclusion we draw may be flawed. The mediation recommended by the AI algorithm may not be right. There are myriad areas of complexity, for instance, our AI classifiers may even be sensitive to the type of camera being used, which may cause higher rates of misclassification for certain types of cameras.

Dr. Benes' and Dr. Kao's concerns about the data quality and inference capabilities were then added to the conjecture map as shown in Figure 6.

Figure 6

Updated Conjecture Map that now includes Dr. Benes' and Dr. Kao's concerns regarding data quality and the AI model's inference capabilities



Note. Updates to the conjecture map are marked in pink.

Judi Fusco: When you suggest something to a student, will that be tracked to whether something is successful or not successful? Will you be able to look into that and have the system learn from those experiences?

Alejandra Magana: That's a very interesting point! We don't have a feedback mechanism currently. We look at cognitive engagement, effective engagement, we might not be able to track the intended effect of having an intervention like that. That's a really good question!

Bedrich Benes and Alejandra Magana: That's a good point. In our proposal, we gave a lot of consideration towards validation. It includes some measurement of central tendencies, analogy testing, the grant has been written some long time ago, we want to find ways to be accountable to our values and goals with this project! We also plan on holding lots of qualitative interviews after we dogfeed [the use of one's own products to work out bugs] our project into the classes that we ourselves are teaching! As Dominic and Bedrich start working with the data we collected last semester, really comparing notes between the hand coding and the algorithm detection will be an important part of the project.

Judi Fusco: Because the system is giving the feedback to the instructor, the instructor is part of the solution. The instructor will choose to intervene or not at that point.

Alejandra Magana: Yes, I wonder how, if the dashboard can provide trends to the instructor (e.g., trending towards being unproductive), and leave part of the decision about whether to intervene to the instructor. This is definitely somewhat of an open question to look into,

Michael Chang: I appreciate how we are making connections up and down the stack, starting from this Alejandra complicating productive engagement detection by making a distinction between productive and unproductive conflict, followed by Bedrich and Dominic talking about their concerns in the data collection, training, and labeling phase which may compound the problem. While this probably felt a bit troubling, I loved how we turned this into the discussion around more expansive possibilities and research where either human (e.g., giving instructors more agency) or technical approaches might be able to mitigate these concerns.

Discussion

Was the adapted conjecture map "natural" to use for interdisciplinary collaboration?

While Dr. Benes and Dr. Kao were first-time users of conjecture maps, their contributions fit naturally into the adapted conjecture map format. While both sides initially spoke from their own perspective about their work, the adapted conjecture map had the appropriate fields to fit those claims. Moreover, once those claims were written in the conjecture map, the adapted conjecture map served as a bridge to connect their ideas. As Dr. Benes and Dr. Kao stated when being introduced to conjecture maps, the format of inputs/outputs in the conjecture map felt familiar from an engineering perspective. This viewpoint is consistent with our conversations with other computer scientists in the field. While this initial comfort is important, it does also raise some concerns that the visual linearity of conjecture maps may lend itself to technological determinism, as conjecture maps (at the surface) do not readily lend themselves towards a discussion about how the subjects of the learning interventions may come to shape the technology themselves. As has been suggested by the past literature (Sandoval, 2014; Wilkerson, 2017), we urge researchers to consider conjecture maps as an evolving tool that is frequently re-visited and updated over the course of a research project, as researchers engage in participatory design work.

While there are many factors that may influence the ease of use of the adapted conjecture map, it functioned effectively in a discussion around the PECAS Mediator. Ultimately, regardless of the tool being used, the most crucial component of the interaction was the coming together of interdisciplinary researchers (i.e., learning scientists and computer scientists), and an openness to the ideas and concerns of individuals with different expertise.

In supporting interdisciplinary research between computer science and learning science, what emerges from the connection made between learning theory and feasible technical capabilities?

As indicated by the concluding statement of the dialogue, the adapted conjecture map, as an artifact, served to make connections between learning sciences theory and computer science capabilities. We found that this connection is a critical enabler of interdisciplinary work between computer scientists and learning scientists. In particular, within this dialogue, the adapted conjecture map's framing around *unintended consequences* proved to be generative between the two sides. In considering how the PECAS Mediator could go wrong, Dr. Magana, Dr. Kao, and Dr. Benes engaged in a provocative discussion around the complex, social nature of collaboration and the limitations of modern technical capabilities. On one hand, Dr. Magana reflects on team-building literature, which indicates that some forms of conflict are crucial towards team-building. On the other hand, Dr. Benes and Dr. Kao reflects on the many challenges associated with AI-based emotion detection and dialogue processing. At this early design stage, the PECAS Mediator is intended to infer team productive and unproductive engagement or disengagement based on the outcomes of these AI classifiers.

In doing this activity, several key questions emerge for the researchers:

- How would an AI-based classifier support instructors in distinguishing between productive and unproductive forms of engagement?
- What more is needed from the learning sciences literature in order to operationalize the findings in a technical system?
- In the absence of technical capability or theoretic clarity about team-building, how could the PECAS mediator come to address the initial concern raised by Dr. Magana?

We view these questions as helping to elucidate a *conceptual tension* between the fields of computer science (specifically, AI) and learning sciences. We believe that the raising of these questions reveals one of the key tensions in interdisciplinary collaboration: technical feasibility. When learning scientists raise concerns or ideas rooted in well-established learning theory, technologists commonly argue that those concerns are not addressable technically. Conjecture maps, by connecting the problems identified as technically feasible with the mediating processes, help to concretize this discussion and provoke discussion about how and whether the boundaries of computer science and learning science theory can be pushed to address the issues raised by the learning scientist.

This dialogue also highlights one of the key tensions between learning sciences and the computer sciences. From a learning sciences perspective, rarely do behaviors fall neatly into containers or categories. On the other hand, computer science solutions thrive when a large number of simplifying assumptions are made about the environment. Given this limitation in computer science-oriented approaches, some of the most fundamental challenges in learning sciences can be difficult to approach (at this juncture) from a purely technical approach.

How can co-design and impacted community engagement support the resolution of conceptual tensions?

At the end of the dialogue, CIRCLS co-PI Judi Fusco invokes a framing that centers the perspectives of instructors, a key user group impacted by a prospective PECAS Mediator. In the dialogue, Dr. Fusco suggests that instructors should be considered "part of the solution;" this shift in framing now gives instructors with their substantial expertise the discretionary power to determine whether an intervention is possible. As Dr. Kao, Dr. Benes, and Dr. Magana were all faculty instructors themselves who envisioned using the PECAS Mediator one day, they were immediately receptive to the framing. The dialogue shifted from how an AI-based solution may be able to effectively determine the presence of unproductive engagement to an AI-based solution that supports instructors in determining whether there is unproductive behavior. Moreover, as Dr. Fusco suggests, this also provides a way for instructors to provide feedback to the PECAS Mediator, allowing it to shift over time to become more effective at detecting unproductive behavior and suggesting mediating strategies.

Not only is engagement with impacted communities critical to the work of responsible innovation, it also represents a way forward for researchers to address "conceptual tensions" from an early stage in their work. Prior to this dialogue, the PECAS mediator team held a strong commitment towards participatory research, along the lines of Responsible Innovation (Stilgoe, 2013). Ultimately, the researchers were able to transform these conceptual tensions into expansive considerations towards how they might engage instructors and other impacted actors in the co-design process. Researchers such as Wilkerson (2017) have demonstrated how conjecture maps can be a powerful way of documenting and analyzing impacted communities' engagement and contributions. We hope to continue discussion with the PECAS Mediator team to see how their adapted conjecture map evolves as they further develop their project and incorporate "human-in-the-loop" type inputs to support teachers in their everyday work.

Conclusion

While researchers have much experience using design-based research to leverage the affordances of technology to push the boundaries of the learning sciences, only recently have researchers undertaken projects to simultaneously push on the boundaries of what is *possible* with computer science and what is *understood* in the learning sciences. To support researchers in this pursuit, we have shared a case study of researchers using conjecture maps to systematically explore this tension. While the conjecture map served as a useful collaboration artifact, the discussion in this study would not have been possible without the mutual respect and openness to new ideas exhibited by the researchers on the PECAS Mediator team. While a tool like a conjecture map may assist researchers in exploring difficult questions around interdisciplinary research, the nature of the collaboration is made or broken by the relations held between the researchers. Collaboration is ultimately fundamentally relational, and we hope that this case study will offer readers an example of how strong relationships and helpful tools together can move researchers towards productive collaborative opportunities.

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