

# Research Statement

Over my career, my research has been driven by several interests: (1) developing new engaging experiences that can make meaningful contributions to users' everyday lives and (2) understanding human behaviors as they interact with interactive artifacts that stimulate learning and problem solving, such as games, simulations, and interactive narratives. A central focus of my work is on developing novel computational methods—including Agent-based systems, AI-driven visualization algorithms, process mining techniques, and discourse analysis frameworks—to model and shape complex human behaviors in interactive systems, aiming to make a social impact in areas such as education, health, and climate resilience. My work is inherently interdisciplinary, integrating techniques from artificial intelligence, machine learning, data science, game design, learning science, and visualization to build interactive systems that are not only engaging but also effective in promoting learning, behavior change, resilience, and well-being.

## 1. Research Projects

My research can be broadly categorized into three interconnected themes: (1) the development of novel, data-driven techniques for modeling and understanding human behavior, (2) the creation of adaptive, personalized interactive systems that leverage these models to enhance the user experience, and (3) pioneering the application of AI technologies to revolutionize education and learning, specifically focusing on metacognitive processes.

Throughout my career, I secured external funding with several collaborators totaling \$36.6M (one large collaborative grant involving 50 researchers and 19 institutions totaling \$23M and other grants totaling \$13.6M), of which around \$10M was devoted to my institution. Of these grants, 7 were granted at UCSC for a total of \$8M (UCSC's part = \$3.8M). This type of funding is rare in my field. Throughout my tenure, I published 5 edited books, two textbooks, 39 Journal papers, and 139 Conference papers. Many of my papers have been published in top venues in my field, and some have received awards. My research has won seven Best Paper awards and three Honorable Mentions. I was named a HEVGA fellow in 2017 for my contributions to the field. Furthermore, in 2024, I was also recognized as an ACM distinguished member and awarded the UC Presidential Chair at UCSC to further my research on AI and education.

Below, I discuss some of my recent work and plans.

### 1.1. Enabling Metacognitive Learning Processes through Analytics and Visualization

Over the past few years, as PI, I led a 4-institution NSF-funded project to develop novel systems that enhance metacognitive learning processes in games for learning applications [1, 2, 3, 4]. This project addressed a critical gap in educational game research. While games generate vast amounts of learning data, there is limited research on how to effectively use this data to guide students in reflecting on their problem-solving processes and analyzing peer strategies. Using a Design-Based

Research (DBR) approach and integrating UX methods, such as participatory design and persona development, we created an innovative AI-based system with an integrated process visualization system for the educational game *Parallel*. A team at Drexel University originally developed this game to teach parallel programming.

The technical challenge involved developing computational algorithms that can develop transparent models of problem-solving for the complex, often spatio-temporal environment of educational games. Unlike traditional learning applications with logical layouts, games involve multiple solution paths and exploratory behavior, creating dense, difficult-to-interpret data visualizations. Our solution involved three interconnected algorithmic innovations. First, we developed a spatial abstraction algorithm that converts raw spatiotemporal game logs into logical zone-based representations, creating adjacency matrices that capture connectivity patterns. Second, we implemented a board state similarity algorithm that uses cosine distance on flattened adjacency matrix embeddings to identify and rank relevant peer strategies across thousands of gameplay traces. Third, we developed a game state recommendation engine that integrates these components with a knowledge graph constructed from expert-labeled states, providing real-time, personalized learning opportunities. This system processes player data in real-time and presents filtered, relevant information through an embedded visualization interface.

Using such an integrated system demonstrated that students were able to successfully utilize visualizations to shift their problem-solving strategies and cognitive processes, thereby helping them assimilate parallel programming concepts. Specifically, such systems helped shift students' thinking process from sequential programming to parallel programming. Students who used the system also demonstrated statistically significant learning gains compared with those who did not.

This work demonstrates the application of advanced data science and visualization techniques to create meaningful learning experiences, illustrating how AI and machine learning can be leveraged to identify patterns in complex behavioral data and present them in ways that promote reflection and learning.

## **1.2. Data-Driven Player Modeling and Analytics**

A significant part of my research has been dedicated to pioneering the field of player modeling and analytics [5, 6]. My work in this area has focused on developing new methods and tools for collecting, analyzing, and visualizing large-scale player data to gain insights into behavior, engagement, and learning, thereby enabling actionable design outcomes. My book, "Game Analytics: Maximizing the Value of Player Data" (2013), was one of the first comprehensive texts on the subject and has been widely adopted in both academia and industry, with over 244,000 downloads and 695 citations to date. Our publisher, Springer, wrote us, "We are delighted to tell you that your book was among the top 25% most downloaded eBooks in its respective eBook Collection in 2018." My more recent book, "Game Data Science" (2021), further extends this work, providing a practical guide to applying data science techniques to game development. This book has been selected for further development into an online class.

My research in this area has led to the development of several innovative techniques for player modeling, including machine learning to identify player strategies, visualization to understand player progression, and human-in-the-loop approaches to behavior modeling. For example, our work on *Glyph*, a visualization tool that uses the Dynamic Time Warping algorithm to identify clusters of thousands of players with comparable problem-solving patterns. This work received the Best Paper Award at the Foundations of Digital Games (FDG) conference in 2015. More recently, we have been developing an interactive visual analytics platform, *INSPECT*, to visualize user journeys and problem-solving behaviors. *INSPECT* combines process mining with real-time filtering and aggregation to handle large-scale behavioral data from commercial applications. *INSPECT* includes features that enable analysts to identify learning patterns and pacing issues within the design. It has been tested within several companies, including an e-learning company, an AI company, and a game company.

### 1.3. Alternate Reality Games for Resilience

A groundbreaking aspect of my research involves developing Alternate Reality Games (ARGs) as novel platforms for measuring psychological constructs, particularly resilience and coping [7, 8, 9]. Through our work on *LUX*, a team-based ARG designed to study coping and resilience among undergraduate and graduate students, we have pioneered a new methodology that addresses significant limitations in traditional psychological research methods.

Traditional approaches to studying resilience and coping rely on surveys, interviews, and controlled laboratory experiments, which suffer from scalability issues, a lack of ecological validity, and an inability to capture longitudinal behavioral processes—fundamental aspects for addressing broader issues, such as mental health, well-being, and anxiety. Our ARG-based approach fundamentally transforms psychological research by enabling us to study constructs in semi-controlled and ecologically valid environments, thereby delivering more effective interventions that can be assessed in real-world settings.

*LUX* is a cooperative and competitive multiplayer team-based game that unfolds on Discord, where participants work in teams of three to solve puzzles by finding clues scattered across campus using augmented reality technology. The game's narrative revolves around UCSC's founding principles, creating an engaging context that motivates sustained participation while generating rich behavioral data.

This work resulted in several technical innovations, including:

- A novel four-phase methodology that combines: (1) comprehensive data collection through Discord chat logs and AR application interactions, (2) qualitative coding of participants' interactions focusing on teamwork, emotional expression, and problem-solving activities, (3) process discovery algorithms that generate process visualizations highlighting team dynamics, bottlenecks, and temporal patterns, and (4) automated identification of coping strategies from process visualizations.
- We employ the Fuzzy Miner algorithm from process mining to generate dependency graphs from event logs, revealing team interaction patterns. Our data collection architecture

integrates a custom AR mobile application with Discord API, capturing multi-modal data (chat logs, AR interactions, timestamps) that we process through a qualitative coding pipeline with inter-rater reliability validation. The resulting process visualizations include temporal indicators that enable automated identification of coping patterns through pattern recognition algorithms.

The work represents a significant technical advancement in behavioral measurement, demonstrating how interactive technologies can be designed to collect multidimensional data about the actions and contexts of hundreds of participants. Unlike traditional laboratory experiments, our ARG platform engages participants for extended periods (weeks), providing longitudinal insights into resilience and coping behaviors that conventional methods cannot capture.

## **1.4. Gamified AI Learning Environments - Extending LLMs for Education**

AI is becoming a central part of our lives and offers numerous advantages in today's educational environments, broadening participation and bridging the accessibility gap by, for example, providing 24-hour multilingual support for students—an ability we have witnessed in our classrooms. However, students may not fully utilize the potential of AI tools due to issues of overreliance, hallucinations, and a lack of metacognitive emphasis in AI design.

One of our current NSF projects focuses on how AI can be used effectively in the classroom. We began by engaging in a co-design process with instructors, teaching assistants, and students to identify the design requirements. Given our emphasis on metacognitive, critical thinking processes, and building on my expertise in game design and AI, we developed a novel approach that embeds metacognitive processes as well as narrative and game elements such as role play, characters, and progression mechanics, to develop an LLM-based agent that can be used within the classroom. This work addresses a critical limitation of current LLM-based educational interactions, which are often described as transactional and repetitive, lacking the narrative richness required to sustain student engagement.

Through participatory design with educators, students, and researchers, we developed the first taxonomy of gamified elements that incorporate metacognitive processes to support learning for an LLM-based agent. This taxonomy comprises 5 dimensions and 19 sub-dimensions, providing educators and prompt designers with a conceptual framework for creating meaningful and engaging learning experiences with LLMs.

Given this taxonomy, we created a novel system that extends LLMs via a prompt engineering framework that embeds metacognitive scaffolding and game mechanics from the generated taxonomy into the conversational flow. Additionally, we developed a real-time student performance analysis module that processes student inputs, classifies them according to our taxonomy of learning acts, and dynamically adjusts the LLM's responses to provide personalized feedback, hints, and challenges. The system maintains a student model that tracks progress across multiple dimensions, enabling adaptive difficulty adjustment and targeted intervention.

This research represents a significant technical advancement in the application of LLM models within education, demonstrating how principles from game design and the learning sciences can be integrated to design AI systems that are not only functional but also engaging and pedagogically effective.

## **1.5. Discourse-Centered Evaluation Methodologies for Collaborative Learning**

One of our recent methodological contributions involves the development of sophisticated discourse analysis frameworks for understanding collaborative learning in serious games, particularly in the context of climate resilience and wildfire preparedness [10]. Through our work with UC Berkeley, we pioneered a discourse-centered, triangulated evaluation methodology that provides unprecedented insights into how knowledge is co-constructed through interaction in game-based learning environments.

Building on the Discourse Acts framework, we developed a comprehensive methodology that categorizes utterances into cognitive, social, and integrative acts, enabling fine-grained analysis of how learners co-construct understanding during gameplay. Our approach goes beyond traditional pre- and post-survey evaluations by capturing the dynamic, socially mediated processes of learning as they unfold in real-time.

Our triangulated approach combines multiple data sources: (1) pre/post surveys measuring confidence, knowledge, and discussion frequency, (2) detailed in-game conversations, (3) game log telemetry, and (4) observational field notes from both onsite and remote sessions. This multi-modal methodology provides a comprehensive view of how resilience emerges in practice. We identified distinct phases of collaborative learning—orientation and setup, prioritization and strategy formation, active collaboration, and reflection and closure—each characterized by different discourse acts that surface prior knowledge and scaffold new reasoning. This temporal analysis reveals how learning unfolds dynamically through socially mediated discourse, providing actionable insights for game design.

Our methodology combines manual discourse coding with computational analysis tools. We developed a system for automated utterance segmentation and preliminary classification, which is then validated through human-in-the-loop review. Further, we created a discourse trajectory visualization system that uses temporal analysis algorithms to map the evolution of communicative acts across gameplay phases, generating graphs that reveal patterns in cognitive, social, and integrated acts. This approach enables scalable analysis while maintaining the interpretive depth needed to understand collaborative learning processes.

This work demonstrates how HCI research can contribute to understanding fundamental learning processes while providing practical tools for evaluating educational interventions. The methodology is transferable across different domains and provides a model for connecting self-reports, interactional processes, and observed behaviors in community-based game studies.

## 2. Future Research Directions

I am excited about the opportunity to continue and expand my research in the following directions:

- **Human-Centered AI for Learning:** I plan to develop explainable AI architectures for educational systems that provide transparent decision-making through attention mechanisms and feature importance visualization. Building on my OPM work, I will extend these techniques to create interpretable student models that both educators and students can interrogate and understand. I am particularly interested in developing multimodal learning analytics that integrate interaction log data, physiological signals, and discourse analysis to create comprehensive models of learning states. This can then enable us to make more adaptable systems that allow metacognitive and regulatory processes.
- **Multimodal AI for Social Good:** Building on my visualization and discourse analysis expertise, I aim to develop AI systems that can process and integrate multiple types of data—including text, speech, gesture, and gameplay data—to create more comprehensive models with situational awareness and context understanding integrated as part of its reasoning process; and thus, enhancing design and potential for broader impacts and social good. Further, I also aim to experiment with different modalities through intelligent interfaces to allow AI to leverage gestures, prompts, indicators, animation, and other modalities in its communication, going beyond text and videos.
- **Scalable Discourse Analysis Platforms:** I will develop semi-automated discourse analysis tools that combine NLP techniques (e.g., transformer-based language models for utterance classification) with human-in-the-loop validation. This will enable analysis of collaborative learning at scale, processing data from hundreds of teams while maintaining interpretive rigor. I envision building an open-source platform that other researchers can use and extend.
- **Novel Interaction Techniques for Learning:** Building on my ARG work, I plan to explore mixed-reality interfaces that blend physical and digital interactions to enhance educational experiences. I am interested in developing adaptive game mechanics that respond to real-time player modeling, creating personalized learning trajectories that adjust difficulty, pacing, and content based on individual and group performance.
- **Design for Social Impact:** Building on my commitment to developing computational experiences for education, learning, health, and climate resilience, I co-wrote a book on the design of serious games, called *Designing Serious Games*. I plan to continue working on designing new artifacts and experiences for social good while developing assessment methods to evaluate their impact.

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