DESIGNING CONTROLLERS FOR COLLABORATIVE PLAY

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Do not be afraid. Play life to the full!

Pope Francis

For Mom, Dad, and Dom. I love you so much.

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SUMMARY

Physical inputs are an integral part of the play-experience in digital games. Recent advances in technology and controller creation have led to a proliferation of a great variety of game controllers outside the console gamepad and mouse-and-keyboard paradigm. These alternative controllers offer a broad space of design opportunities and can be configured to support a wide variety of interaction types and amplify digital game mechanics. Alternative controllers are particularly well-suited to collaborative play contexts because they may be designed to take multiple or complementary inputs and thus support multiple simultaneous users. However, there are few resources specific to collaborative alternative controllers available to designers.

My work applies cognitive approaches to human-computer interaction to play to generate a holistic understanding of the relationship between the physical affordances of controllers and the sense-making experiences of players. This allows for the generation of actionable design guidelines that take into account both physical design choices and players' social experiences and the establishment of a novel means of quantifying collaborative embodied gameplay. This dissertation includes four primary contributions: 1) the development of three themes and a taxonomy for collaborative alternative controllers; 2) the documented development of three boundary objects for the purpose of investigating players' sense-making processes with each; 3) the first use of creative sense-making analysis to describe and quantify goal-oriented embodied collaborative play; and 4) a series of design principles developed from an annotated portfolio of the boundary artifacts developed for this thesis and annotation of creative sense-making curves for each. In addition to contributing specifically to the field of alternative game controllers and design for collaborative play, this work contributes to research in games and play studies, tangible and embodied interaction design, and human-centered computing.

CHAPTER 1

INTRODUCTION AND BACKGROUND

1.1 Motivation

Alternative game controllers — physical input mechanisms for interactive media that are distinct from traditional console-affiliated handheld controllers or computer inputs such as mice and keyboards — are a growing design space in digital games, owing largely to the democratization of the creation of artifacts with programmable microcontrollers and the widespread availability of consumer electronic toolkits. While non-traditional controllers have had a home in arcade spaces for decades, the popularity of games and art festivals for custom controllers — that may be designed for humor, novelty, or accessibility [1, 2, 3, 4] — and a significant presence within streaming media [5, 6, 7, 8], marks a substantial public interest in such objects outside of arcade settings. As is the case with "game," the term "alternative controller" is difficult to define. It is likely that such a definition must allow for fuzzy boundaries, similar to those found in works seeking to define what a game is [9].

Stenros' cluster theory approach suggests that the definition of game includes multiple features (such as "rules governing action" and "results or pay-off"), and the more of these features something has, the more likely it is that it is a game [9]. "Traditional controllers" may be described in a similar fashion, with the term "alternative controller" describing those artifacts that are less likely to have many features from the "traditional controller" category. Features of traditional controllers include physical forms that do not resemble other objects, generalizable controls (buttons or axial controls defined by their location or letters, numbers, or shapes used as identifiers), and widespread use or mass-production for inclusion with one or more popular game platforms. A cluster theory approach would define a given game controller as more or a less a member of the “traditional controller” category based upon how many of these properties it includes..

“Alternative” controllers can be considered as defined in opposition to “traditional’ controllers; the less a controller belongs to the “traditional controller” category, the more it can be considered to belong to the “alternative controller” category. This approach places “alternative mainstream” controllers such as *Rock Band* peripherals and the Wiimote in a “middle ground” between the traditional and the entirely alternative, and controllers such as the pudding bowls from v21’s *Punch The Custard* as least likely to belong to the “traditional controllers” category.

Alternative controllers are particularly well-suited to collaborative play contexts because they may be designed to take multiple or complementary inputs and thus support multiple simultaneous users. ”Collaborative play“ as used in this thesis encompasses any play in which multiple interactors share responsibility for some output or outcome of the activity. This includes play in which teams of players compete against one another (where collaboration occurs within a team), play in which players for temporary alliances, and more conventional cooperative play in which all players succeed or fail together. There are currently few resources specific to collaborative alternative controllers available to designers. Typically, creators of alternative-control games must draw on design knowledge from a variety of related fields rather than more targeted principles that account for the unique properties of alternative controllers. My work applies cognitive approaches to human-computer interaction to play to generate a holistic understanding of the relationship between the physical affordances of controllers and the sense-making experiences of players. This allows for the generation of actionable design guidelines that take into account both physical design choices and players’ social experiences and the establishment of a novel means of quantifying collaborative embodied gameplay.

The wide design space of alternative controllers — unconstrained by the traditional user-experience notions of ease-of-use, transparency, and efficiency — offers designers

Figure 1.1: *Loominary* system for visualizing narrative choices, from Sullivan et al., 2018 [10]

Figure 1.2: *Rope Revolution* system for collocated and remote social play, from Yao et al., 2011 [11]

great flexibility in creating playful experiences, which allows for design that supports a multitude of interaction types. Alternative game controllers can be designed to support and augment a variety of player experiences. They may heighten enjoyment and presence [12], visualize narrative choices [10], and facilitate remote social play [11]. Many forms of play are fundamentally social activities, and cooperative gaming is an immensely popular activity among game players [13]. Design for social playful experiences is not only relevant within games, but extends further into the realms of installation design and other forms of collaborative tangible media.

Connecting the multitude of approaches for controller and interactive media design to the play and sense-making activities of users is primarily an unanswered challenge. Studies of various design choices in games have enumerated a number of ways in which the design of sound, dialogue, environments, and characters relate to player actions during gameplay. However, this type of study largely focuses on a particular outcome variable, such as social closeness [14], emotional response [15], or immersion [12]. These approaches, while distinctly useful in designing for various player responses within a specific domain, do not cover the broader trajectories of a play session.

Practice-focused game design literature often centers on approaches to game design aimed at generating entertaining interaction. Best practices and recommendations in this field are largely derived from industry practices rather than formalized study [16, 17], and are thus limited to covering design techniques for mass-produceable games within one or multiple existing genres. This practice, centered heavily on existing work, limits our understanding of how to design physical affordances for patterns of collaborative play, which is a smaller and relatively newer field with fewer extant artifacts. Additionally, such literature rarely covers controller setups beyond what is assumed to be typical due to challenges in mass-producing and selling custom controllers for large audiences. As more alternative-control works are created and exhibited at games festivals and similar events [3, 1], it becomes necessary to investigate and formalize a language with which to discuss, conceptualize, and evaluate them.

Creative sense-making, a cognitive framework that applies the concept of participatory sense-making to the creative domain, offers an apt lens for deepening the field's understanding of the relationship between controllers and players' experiences by taking into account both embodied action and social cognition [18, 19]. Both participatory and creative sense-making, which have grown from the enactivist paradigm, consider both embodied action and social interaction as key components of social cognition. Given the fundamentally embodied, social, and improvisational nature of collaborative alternative game controllers, creative sense-making is a potentially ideal lens for examining the means by which players make meaning via their experience of controllers and one another. It can be used to capture the joint activities of players over the course of a full play session, which can be used to describe the trajectory of play.

My work seeks to remedy the gap in understanding between controller design and patterns of play by analyzing dyadic (two-player) collaborative play with alternative controllers through the lens of creative sense-making, connecting these analyses to design knowledge about alternative controllers from the literature, and offering a robust understanding of the interactions between alternative controllers and players' social cognition. Through the creation and creative sense-making analysis of three playful, interactive artifacts, a richer understanding of the interplay between physical affordance and play becomes possible. This work provides actionable knowledge for the designers of future systems that promote playful social experiences, such as designing in-game events that prompt reneogtiation of strategy or controller use by interrupting coupled play.

1.2 Thesis Statement

Understanding the relationship between the physical affordances of alternative controllers and the creative sense-making patterns of players can yield new insights into designing games and controllers that promote collaborative patterns of play.

1.3 Research Questions

- **RQ1:** How does creative sense-making play a part in how people collaborate in embodied collaborative play?
  - RQ1.1: Can creative sense-making states be used to describe actions in embodied collaborative play?
    - **Objective:** Using existing creative sense-making literature and observations from study sessions, develop lists of behavioral markers that corre-

spond to creative sense-making states during interaction with each artifact/condition.

    * **Outputs and measurable outcomes:** Creative sense-making codebooks for video data of interactions with each artifact/condition.

  – RQ1.2: Can patterns of creative sense-making be discerned from analysis of embodied collaborative play?

    * **Objective:** Using the codebooks developed as part of RQ1.1, analyze video data of player sessions for each artifact/condition and produce creative sense-making curves for each pair of interactors.

    * **Outputs and measurable outcomes:** Creative sense-making curves for all sessions quantifying and describing collaborative sense-making trajectories; description of observable patterns within/across artifacts/conditions.

- **RQ2:** How do the physical affordances of alternative controllers correlate to features of the creative sense-making experiences of players?

  – RQ2.1: Can creative sense-making patterns from embodied collaborative play sessions be mapped to the physical affordances of the controller used?

    * **Objective:** Compare characteristics of sense-making curves from game sessions with traditional and alternative controllers.

    * **Outputs and measurable outcomes:** Creative sense-making descriptions of differences in patterns of collaborative play with traditional versus alternative control conditions.

  – RQ2.2: Do generalized creative sense-making curves from embodied collaborative play sessions with different alternative controllers exhibit different properties?

    * **Objective:** Compare characteristics of sense-making curves from sessions with three distinct alternative-control artifacts.

        * **Outputs and measurable outcomes:** Creative sense-making descriptions of differences in patterns of collaborative play with alternative controllers with varying physical affordances.

- **RQ3:** How can creative sense-making analysis of play with collaborative alternative controllers yield generalizable knowledge for the design of other artifacts of the same type?
    - RQ3.1: Can observed events in embodied collaborative play sessions be mapped to creative sense-making states or changes in creative sense-making states during an embodied collaborative play session?
        * **Objective:** Annotate creative sense-making curves from alternative-control play sessions with timing of observable play events; describe any observable patterns in sense-making curve characteristics before or after events.
        * **Outputs and measurable outcomes:** Descriptions of interplay between play-events and sense-making processes of players.
    - RQ3.2: What design guidelines can be developed for the creation of alternative controllers that promote patterns of creative sense-making?
        * **Objective:** Using observed sense-making patterns from RQs 2.1, 2.2, and 3.1, annotated sense-making curves, produce intermediate-level design guidelines for applying knowledge gained from this analysis to future artifacts of a similar type.
        * **Outputs and measurable outcomes:** Series of design guidelines for developing alternative-control games and playful experiences.

1.4 Thesis Overview

The next chapter of this thesis covers the methodological approach taken to investigate these research questions. Chapter 3 lays out background literature in the fields of controller history and design, game design practice for collaborative play, and participatory and creative sense-making. I propose three themes for collaborative controllers based upon the literature and existing work, and discuss several existing artifacts as they relate to each theme for collaborative controllers. Chapter 3 closes with a taxonomy for collaborative controllers based upon these themes that may be used to describe shared and disparate characteristics of collaborative alternative-control artifacts.

In Chapter 4, I present an overview of the three boundary artifacts designed to support this thesis, positioning them using the taxonomy from Chapter 3 and highlighting relevant design choices for each. This chapter gives an overview of the design process, a technical description, and a description of user studies conducted for each artifact. Chapter 5 provides a detailed description of the creative sense-making analysis process, including codebook development (**RQ 1.1**), and production and annotation of creative sense-making curves for each artifact and condition (**RQs 1.2, 2.1, 2.2**).

Chapter 6 discusses the development of mappings between artifacts' position using my taxonomy and properties of their sense-making curves (**RQ 3.1**). These mappings support the design guidelines developed from my work (**RQ 3.2**). Finally, Chapter 7 covers discussion of the thesis work in terms of its outputs, limitations and directions for future research.

1.5 Definitions

Provided in this section are definitions of terms as they are used in this thesis.

1.5.1 Alternative Controller

As used in this thesis, an *alternative controller* can be defined as a physical input mechanism for interactive media that are distinct from traditional console-affiliated handheld controllers or computer inputs such as mice and keyboards. This definition is not exhaustive and leaves substantial room for interpretation; however, it is more than sufficient in describing the artifacts discussed here.

1.5.2 Sense-Making Terms

Sense-Making

De Jaegher and Di Paolo provide a concise definition of *sense-making* as "the creation and appreciation of meaning" [19]. This definition assumes a sense-making agent that interacts with the world in a way "significant to the cogniser" to gain information about its surroundings [19].

Participatory Sense-Making

In this thesis, I use *participatory sense-making* as defined by De Jaegher and Di Paolo in 2007: "the coordination of intentional activity in interaction, whereby individual sense-making processes are affected and new domains of social sense-making can be generated that were not available to each individual on her own" [19].

Creative Sense-Making

Creative sense-making, defined by Davis et al. in 2017 as a concept grown from participatory sense-making, refers to a framework that draws on participatory sense-making and the authors' empirical investigations of creative activity during open-ended play . *Creative sense-making* describes embodied creative interaction as a series of states alternating between *clamped cognition*, where an agent acts based upon its mental model of a situation, and *unclamped cognition*, in which the agent disconnects either physically or perceptually from the task at hand in an attempt to refine its mental model [18]. The framework, as described by the authors, allows for the *quantification of interaction dynamics during open-ended creative activity*.

CHAPTER 2
METHODOLOGICAL APPROACH

My methodological approach can be viewed as part of the broader *research through design* paradigm, in which the activity of designing artifacts, as well as the artifacts themselves, comprise a key component of inquiry [20]. Within research through design, "design practice is brought to bear on situations chosen for their topical and theoretical potential, the resulting designs are seen as embodying designers' judgments about valid ways to address the possibilities and problems implicit in such situations, and reflection on these results allow a range of topical, procedural, pragmatic and conceptual insights to be articulated" [20].

This approach centers upon three primary activities. The first is the design and implementation of three alternative-control (and one traditional-control) games and playful experiences, which supports two primary research outputs. The first output is the artifacts themselves, which "embody the myriad choices made by their designers with a definiteness and level of detail that would be difficult or impossible to attain in a written (or diagrammatic) account" [20]. Designing new artifacts rather than using existing artifacts was necessary to support analysis of player experiences with particular combinations of physical affordances. Without artifacts representing specific affordances, the analysis of the relationships between those affordances and players' sense-making activities would not be possible. The second output of these designs is documentation collected throughout the design process, outlining design choices and modifications as the controllers and games were developed, in order to support the inquiries made in the second and third research activities.

Table 2.1: Methodological summary, organized by RQ.

RQ	Research Question	Methodological Approach
RQ1	**RQ1.1:** Can creative sense-making states be used to describe actions in embodied collaborative play?	Development of creative sense-making codebooks for each artifact; use of codes to analyze video data from user studies
	RQ1.2: Can patterns of creative sense-making be discerned from analysis of embodied collaborative play?	Creative sense-making analysis of video data from user studies; inspection of resulting sense-making curves for general patterns in play with each controller
RQ2	**RQ2.1:** Can creative sense-making patterns from embodied collaborative play sessions be mapped to the physical affordances of the controller used?	Comparison of sense-making analyses of *Haber Dasher* sessions with hat controller and sessions with gamepad
	RQ2.2: Do generalized creative sense-making curves from embodied collaborative play sessions with different alternative controllers exhibit different properties?	Comparison of sense-making analyses of sessions across all three alternative controller artifacts
RQ3	**RQ3.1:** Can observed events in embodied collaborative play sessions be mapped to creative sense-making states or changes in state during an embodied collaborative play session?	Plotting of event points and gameplay data (e.g., coffee spills in *Haber Dasher*) on sense-making curves; observation of any associated changes in creative sense-making state near event points
	RQ3.2: What design guidelines can be developed for the creation of alternative controllers that promote patterns of creative sense-making?	Development of design guidelines for collaborative alternative controllers using creative sense-making data

The second is the analysis of video data from user sessions with these boundary objects and development of joint sense-making trajectory curves for each. Unlike approaches that measure outcome variables (e.g., social closeness, enjoyment, immersion) after play has ended or approaches that track player metrics within a digital game (e.g., events logging), creative sense-making offers an account of players' activities and collaborative processes throughout the entire play-session. A grounded theory-based coding approach to analyzing play-sessions may also yield this result; however, the creative sense-making framework, which has already been developed and focuses specifically on joint sense-making processes, allows for much more rapid analysis of play sessions and thus the analysis of a greater amount of data. The increased analysis speed is a considerable advantage when investigating a large number of play-sessions across multiple artifacts, as is the case in this thesis. Creative sense-making analysis, presented in concert with the designed physical affordances of the artifacts themselves, supports the generation of generalizable design knowledge, such as the design guidelines presented in Chapter 6 of this thesis.

2.0.1 Boundary Artifacts

A primary component of the work in this thesis is built upon the development of three alternative-control artifacts to support investigation of my research questions. The three artifacts developed or this purpose are intended to probe the boundaries of the alternative control space. The development of each was accompanied by design notes during and following the period of development that supports the use of the artifacts and design processes themselves as exemplars for use in guiding the development of the design guidelines presented in Chapter 6.

I propose a series of three nested themes for as well as a translation of these themes into a taxonomy for collaborative controllers, which is described in detail in Chapter 3. The artifacts developed for this thesis are intended to probe the boundaries of the collaborative controllers space by examining artifacts that approach the three themes for collaborative controllers using highly disparate physical affordances. This aim guided the selection and design of each artifact, a process that is described in greater detail in Chapter 4.

2.0.2 Creative Sense-Making Analysis and Design Guidelines

Davis et al.'s creative sense-making framework is ideal for understanding collaborative, embodied play. The framework, due to its relative novelty, has seen some use use in analyzing embodied, collaborative activities (such as dance and sketching), but draws from the more broadly-recognized participatory sense-making framework. Participatory sense-making analysis has previously been applied to a wide variety of collaborative efforts, including musical improvisation [21], language [22], therapeutic interventions [23], online learning [24], and digitally-augmented music [25]. The framework is widely applicable to a large number of socially embodied settings, and takes into account the sense-making processes of each individual as well as "new domains of social sense-making...that were not available to each individual on her own" [19].

The selection of creative sense-making over participatory sense-making draws from the key advantages it offers in describing playful interaction. The first lies in the creative sense-making framework's ability to quantify sense-making dynamics. The ability of creative sense-making categories to be translated into numerical values allow for the production of curves that can be analyzed mathematically, which allows for the generation of additional descriptors of an interaction that would not have been possible otherwise, including descriptions of an interaction as a continuous series of joint sense-making states. Further, the creative sense-making framework supports this numerically-based modeling in multiple domains, allowing for comparisons between interactions with highly disparate artifacts. Finally, coding for creative sense-making states is substantially less time-consuming that a traditional thematic analysis; while this alone would not be a good reason to choose one over the other, use of creative sense-making has allowed for hte inclusion of more artifacts than would have otherwise been possible, and the speed of analysis can be considered an additional advantage of the framework.

In addition to using creative sense-making analysis to produce creative trajectory curves for interactors engaged in play with the artifacts developed for this thesis, I employ additional levels of analysis to expand upon this data. Creative trajectory curves from each dyad have been augmented with highlighting of creative sense-making states (using modified criteria from Davis's formal descriptions of joint sense-making states [26]), plotting of in-game events along the curves, and annotations drawn from live and retrospective observer notes. Selected trajectory curves are presented along analyses presented in Chapters 4 and 5. In Chapter 6, I present a series of five design guidelines, generated from the designed properties of the boundary artifacts and their mappings to creative sense-making processes outlined by the analysis of each.

2.1 Contributions

2.1.1 Documented exploration of the design space via creation and analysis of boundary objects

A primary component of my work is the design, creation, and analysis of boundary artifacts within the realm of alternative controllers. The design of each was guided by the design themes *safety*, *social spaces*, and *interreliance* (described in greater detail in chapter 3), drawn from literature in games studies, game design, and tangible interface design. These themes, another contribution of this work to the field, offer a novel framework for conceptualizing and classifying alternative-control games and playful interfaces. The artifacts developed for this thesis are meant to explore distinct strategies for approaching these three themes, and disparate means of addressing each theme provided key elements of the design of the artifacts.

The three boundary artifacts developed for this thesis approach these themes using a variety of approaches, which is intended to explore disparate means for designing for collaborative play with alternative controllers. Two of these artifacts are games: a two-player game where players share a large, wearable hat controller and a two-player game in which players use asymmetrical controls to guide a virtual spaceship through an asteroid field. The third artifact is an open-ended interactive installation that uses colorful beach balls to generate musical output. In contributing to a growing body of work within the alternative controller space, I expand upon previous theorizing and experimentation by defining new points in the design space and pairing them with analysis that situates them among existing artifacts.

2.1.2 Application of creative sense-making curves to describe collaborative play patterns with alternative game controllers

Play is an activity that relies heavily on improvisation in generative activities such as collaborative pretend play and in goal-oriented situations such as games. Davis et al. [18] found creative sense-making to be an apt framework for describing dyadic, improvisational pretend play and representing players' introduction of new ideas to the play-world and subsequent negotiation of narrative between players. In playing a collaborative game, particularly with an unfamiliar controller, players must generate meaning, coordinate actions, and develop a shared approach to play, all of which relies on improvisational social action not unlike that undertaken by individuals involved in pretend play.

I postulate that the creative sense-making analysis proposed by Davis et al. [18] is appropriate for the analysis of dyadic play with alternative game controllers given the embodied and exploratory nature of the activity. In the application of creative sense-making as a lens to understand controller-mediated play, I illustrate that creative sense-making processes indicate important patterns in embodied playful collaboration. These patterns can yield new insights into design for such activities. The use of the creative sense-making framework offers a quantitative means of describing interaction with games and playful media, as well as with the controllers that mediate such experiences. The resulting creative sense-making curves uncover new insights about the ways people collaborate in playful settings. This thesis represents the first case of creative sense-making being applied to describe collaborative, goal-oriented play; previously, the framework had only been applied to open-ended, improvisational activities, such as pretend play and collaborative sketching [18].

2.1.3 Documentation of correlation between game and controller design and players' creative sense-making activities

I hypothesize that there is a relationship between the affordances of alternative controllers (and the experiences they mediate) and the creative sense-making patterns of players. The work presented in this thesis is intended to investigate this claim and yield insights into the play-patterns of interactors. The development of mappings between controller affordances and players' sense-making activities is detailed in Chapter 5. I contend also that the information generated by this investigation offers game and controller designers additional knowledge on which to rely when designing and situating new artifacts; this documentation and mapping supported the generation of generalizable knowledge in the form of design guidelines.

2.1.4 Design guidelines for alternative controller design to promote patterns of creative sense-making

This thesis outlines a series of preliminary design guidelines that transform the correlation and descriptions developed from my research into actionable design guidelines. While these principles are most useful within the specific space (alternative controllers to promote collaboration) for which they are developed, they will additionally be relevant in related fields, most notably installation design and adaptive controller design. Though these realms do not often aim for the same goals as play for entertainment, there is substantial overlap among them in terms of design practices and processes. The principles developed as part of this work have been published and made freely accessible to support the creation of game controllers, installations, exhibits, and other playful artifacts that seek to promote collaborative ludic activity.

Design Guidelines

- DG1. Promote coupled play with goals or promote exploration with open-ended play.
- DG2. Prompt renegotiation of controller use with interruptions in play.
- DG3. Encourage exploration after interruptions with novelty.
- DG4. Encourage exploration with multiple axes of control and/or distributed controls.
- DG5. Focus information exchange or coupled action by tuning shared attention.

CHAPTER 3
BACKGROUND

Game controllers have been recognized in recent years by games scholars as vital but under-theorized components of the digital gameplay experience [27, 28]. Blomberg theorizes that the game controller occupies a unique space as the mediator between the physical world and the world of a digital game, additionally arguing that the "video game experience is enabled, shaped, and formed by material preconditions like a specific hardware with a specific input device" [27]. Despite this key positioning within the digital game experience, the controller is often overlooked or assumed to support transparency as much as is possible. Contemporary control schemes draw from decades of mouse-and-keyboard and handheld-control paradigms, which have become so ubiquitous that designers are able to make assumptions about players' familiarity with conventions such as "press A to jump" or WASD controls. These conventions are particularly useful for designers who wish to leverage their players' familiarity with standard control patterns to forefront other elements of play.

Such effort towards invisibility, however, causes great reduction in the types of experiences that may be afforded within the digital games space. Controllers offer a rich space for the disruption of conventional game design practices, and rejection of transparency can be utilized towards a number of ludic ends, (e.g., increased immersion [12], accessibility (as with Xbox Adaptive Controller), or queering games [29]). The creation of controls outside established paradigms opens an expansive design space within which entirely novel player experiences may be created through the design of new media for interacting with digital games and other playful artifacts.

Alternative game controllers have gained widespread appeal in recent years in popular culture, owing largely to democratization of creation and an expansion in streaming media. Technologies such as consumer-programmable microcontrollers like the Arduino Uno and other consumer-grade controllers such as Joylabz's *Makey Makey* make the creation of unique controllers accessible to individuals with a large range of manufacturing and programming abilities. There is a thriving alternative controller festival scene; Alt.Ctrl.GDC is a dedicated outlet for such works, and other events such as Indiecade include games with alternative controllers among their nominees. Additionally, there is a substantial body of alternative-controller streaming media present online. Content creators such as Rudeism and SuperLouis64 reap tens of thousands of views on videos of them playing various games with custom, often humorous, controllers [7, 6, 5, 8].

A key affordance of alternative game controllers is the inherent flexibility in design they offer creators. While traditional controllers shipped with game consoles must be mass-produced, and control schemes for PC games largely take advantage of existing keyboard-and-mouse PC control paradigms, alternative controllers are not bound by requirements of mass-production or input efficiency; constraints for alternative controllers are the much wider restrictions to controllers that are physically possible to build and program. When not restrained by ideals of usability or simple manufacture, designers are free to experiment with novel configurations and interaction systems. Such freedom in form and function can be directed in any of a number of directions; the removal of these constraints widens the space of controller design to encompass anything that may be supported by the current state of technology.

Flexibility of design, combined with the relative novelty of unique alternative controller design as a practice, means there is little formal inquiry with regards to the ways the physical affordances of such devices may be used to support different patterns of play. Literature from the fields of human-computer interaction and play studies lend paradigms useful for approaching a more robust understanding of design for embodied playful interaction. Three design themes emerge from the literature, and from existing works in the field of alternative controllers (both those designed to facilitate collaboration and otherwise) that support the creation of such experiences. These themes support the categorization of collaborative controllers along three axes, which is described in Sections 2.2 and 2.3.

3.1 Historical and Contemporary Approaches to Custom Controllers

Contemporary approaches to alternative controllers reflect several key aspects of controller design for home and arcade use, starting with the introduction of inputs for digital systems and extending through the coalescence of the contemporary gamepad and commercial and independent explorations of ways twenty-first century technologies could support new forms of input in the home and beyond. Lessons for modern alternative controls can be drawn from the full history of game controllers, beginning with the custom electronic inputs developed for the earliest computer games. From these early artifacts, designers can draw approaches that center on mapping controllers' physical forms to individual game actions, as the first game controllers did. As games evolved and found spaces in the home and in arcades, a variety of controllers beyond the mainstream were developed. Arcade games, which have greater spatial resources, offer lessons in designing for large-scale and public interactions; mainstream in-home controllers provide contrasts to alternative controller design approaches; and the array of alternative controllers for consoles developed over the years provide a foundation for theorizing about similar contemporary or future artifacts.

Though alternative controllers have seen a great expansion in recent years due to technology access and increasing outlets for showing such work, there exists a substantial history of alternative controllers leading to the contemporary design scene. The first game controllers could not, and thus did not, subscribe to control conventions that were established over the course of following decades. Often, controllers were designed to support specific games, such as the dual-dial controller that was included with home versions of *Pong* [30] and gun-shaped controllers shipped with various shooting games. In these systems, controllers took multiple forms owing to a lack of established design paradigm for game inputs. Instead of generalizable controllers, each games' input devices were designed as an immediate mapping to player actions in-game: dials or joysticks to control motion; switches and buttons mapped to single in-game actions, and the like. Controllers in this period included various combinations of buttons and joysticks as well as “gloves with built-in sensors, wired pads or platforms to be controlled with your feet or body weight”[30].

Arcade cabinets, which could take advantage of larger spaces and did not have to be generalized for multiple games, were a space with greater controller variety. Even as home console controllers converged in their designs, arcade controllers remained a category of artifacts that leveraged game-specific inputs. Examples of these inputs can be seen in contemporary arcade spaces, which often including replications of car seats, pedals, and steering wheels for racing games, guns for shooting games, dance pads for dancing games, and a wide variety of newer interfaces as well. A contemporary example that illustrates custom-control arcade game design practice is the rhythm game *Chrono Circle*, which rings its circular touchscreen display with with buttons; both the buttons and the touch screen are used during play [31].

As home consoles grew in popularity and needed to support a larger variety of games, controller design converged, with the emergence of the Atari 2600 joystick and then the NES gamepad [30], a “more universally applicable device”[32]. As home-console controllers evolved further, this universal applicability remained a goal even as additional d-pads, thumbsticks, and shoulder buttons were added. Commonly used controllers grew more complex, but remained highly generalizable using the gamepad format, which remains the model for controllers shipped with current-generation Xbox and Playstation consoles. As several commercial control schemes emerged and eventually converged , a small number of “alternative” commercial controls also arose (steering-wheel controls, dance-pad controls, glove-based controls, microphones, guitars, and even drums in the case of Nintendo’s *Donkey Konga*[33])). These commercial controls, frequently inspired by arcade counterparts but sized and configured to support use in the home, were met with varying levels of commercial success. Despite this, gamepads still reigned supreme, owing to their ability to provide a generic controller type that supports a broad array of interactional mappings.

The convenience of the gamepad design was and remains highly advantageous for game designers. The contemporary gamepad offers a number of abstract components that may be used as inputs for a large variety of game mechanics. The conventions that have developed during the decades of the gamepad's popularity (pressing A to jump, using a trigger-like shoulder button to shoot) gives creators of games within popular genres existing control scheme paradigms to work within. Further, the contemporary gamepad allows for players to build fluency across hours of gameplay, enabling the physical input for a gaming system to become a transparent tool. In these settings, the controller is subsumed by the experience of play; the player does not consciously consider the pressing of the button or the moving of a joystick, but plans and executes actions in the real world while focusing on the input's effects in the game world.

This is not to say the gamepad has entirely erased other kinds of controllers. The early years of the 21st century saw the introduction of several new commercial forays into non-gamepad controls, which included developments such as the WiiMote, EyeToy, and Kinect [30]. Advancements in technology enabled the creation and marketing of such controls, but companies were and are still limited to the constraints of what can be mass-produced and used to support a variety of games on a console. Perhaps the most notable development of this period was the release of the Nintendo Wii in 2006 which broke with gamepad conventions and relied instead on motion tracking [30]. The advancement of technology has allowed for further explorations in the years since, and it is reasonable to presume that new developments in consumer alternative controllers will continue in coming years.

Also recently resurgent are alternative controllers that are designed for use outside the home in non-arcade settings. Rather than being designed for permanent use as money-making arcade installations, these artifacts typically make appearances at games festivals and other events where temporary public art may be installed. These games and controllers are often developed by small, independent designers who leverage commercially-available technology to produce novel play experiences. Developments in making technology, including the low cost and availability of the Arduino series of microcontrollers and consumer-model 3D printers have allowed hobbyists and independent artists to engage in production activities that would not have been previously possible. In addition to games festivals and similar events, these artifacts have also become popular content on Youtube, Twitch, and other outlets for streaming video. Like arcade games, these artifacts are not required to be mass-produceable, and can be designed to support game-specific interactions and large-scale inputs.

3.2 Themes for Collaborative Alternative Controllers

The existing body of alternative controls work, which spans academic, industry, and independent creator spaces, offers a wide variety of exemplar artifacts that reflect designers' approaches to creating controllers to support collaborative play, which encompasses

I have synthesized information from these works to propose a trio of themes by which the flexible and user-novel design of alternative controllers may support collaboration in play: *Safety*, *Social Spaces*, and *Interreliance*. These themes may be used to conceptualize alternative controllers, position them in the design space with relation to one another, and can additionally be used in a generative capacity in the early stages of game and controller design. Each of these relies on and builds upon the theme before it; in order to create a playful experience that successfully engages players in a social space, players must first feel socially safe interacting. Interreliance, similarly, requires that players are able, willing, and encouraged to take on the roles asked of them by the magic circle so they may experience the interplay between those roles.

Figure 3.1: Visual representation of the nested nature of the three themes for collaborative controllers.

Table 3.1: Several methods of fulfilling each theme for collaborative alternative controllers.

Safety	Social Spaces	Interreliance
• Novel/Unfamiliar • Shared • Humorous • Unwieldy	• Large • Visible • Wearable • Forces proximity	• Physically Shared • Multiple players control one avatar • Asymmetrical • Multiple components

3.2.1 Safety

In order for potential players to choose to engage in any playful experience (including a collaborative one), they must first feel socially safe playing in the first place, and must be willing to engage in play. *Safety* identifies means by which a controller (and the accompanying game) allows for a play experience in which players' feelings of self-consciousness may be mitigated to reduce discomfort with the interaction. While other types of safety, such as physical safety, are important considerations in game and controller design, social safety is of particular concern in collaborative play contexts due to the inherently social nature of collaborative interaction. Trust and safety, especially social safety, as theme of play appears in the works of a number of important play scholars. Salen and Zimmerman [34], as well as de Koven [35] highlight the importance of creating safety and trust within the play-space. Play requires the player to agree to a "contract for artifice" in which all players must "buy in" to the game's fiction, and agree to be bound by its rules [34].

Though games scholars may disagree as to the exact nature, positioning, and boundaries of the magic circle [36, 34], they generally agree that the play-space or play-community has boundaries of some sort and must include some element of safety among its members [37, 38]. The notion of "safety" may be used to describe the stakes within the play-space as necessarily lower than those of "real life," or may refer the related idea that players must feel they will not be judged or harmed socially based upon their actions within the play-space. Safety as a key theme for collaboration in games draws primarily from the latter conception of safety, drawing heavily from Salen and Zimmerman's and De Koven's conceptions of trust in play [34, 35]. De Koven in particular emphasizes the entrance of players into a self-sustaining play community in which, for a "well-played" game to occur, all actors must trust that the others intend to play well together: "The safer we feel in the game we're playing, the more willing we are to play it"[35].

A play-space that successfully supports interpersonal interactions (collaborative or otherwise), must then engender some construction of player safety, or at very least offer a space within which players may trust one another. Players must be able to believe that others who enter and engage with the space will not cheat, ruin the game, or break the boundaries, however firm or pliable, of the play-space. The boundaries are precarious; should even one individual enter the play-space but reject the social contract for artifice, the boundaries are diminished and may dissolve entirely. Huizinga's "spoilsport" ruins the play-activity, rejecting artifice and "threatening the existence of the play-community" [36]. Designs that promote feelings of social safety should prevent "spoil-sporting" as much as possible, thus decreasing the perceived social risk of interactors and allowing them to fully participate in play.

The challenge of developing a play-space that engenders feelings of safety is particularly relevant in designing playful spaces for adult users. Some types of play among adults may be seen as embarrassing, and this social hurdle may cause reluctance to enter into a playful interaction [39]. If players feel as though engaging in a game (or with its controllers) presents a level of social risk which they are uncomfortable with, no play can occur. In order to take on the roles endowed by the magic circle and engage in interreliant play, players must first feel comfortable becoming part of the game. The theme of safety addresses this concern. Design for play-spaces that can be perceived as safe for social interaction can remove some of the barriers to social safety, and the work of multiple play theorists describe varying means of achieving player safety from a design perspective.

These barriers, in order to be counteracted, must first be identified. Works from play scholars focused on both social risk in play and more general design work include descriptions of multiple aspects of play that increase social risk. Identifying the variety of risks presented by alternative-control play allows for the design of game mechanics and controller properties to mitigate those risks. Voida and Greenberg's work on the console as computational meeting space outlines barriers to play with game consoles more generally, but controller interaction is included as a key consideration within this depiction: "Without exception, every gamer who spoke about selecting a gaming platform that would be appropriate for a breadth of expertise levels cited the input device as the central factor in the decision-making process. Input devices that afforded simple motion were preferred. Input devices with a lot of buttons were generally rejected as having too much of a learning curve" [40]. While this investigation covered mainstream console gaming, controller performance considerations were also key in Love and Bozdog's considerations in the development of *Ola de la Vida*, in which the "leveling effect" of the unusual controller is cited as a major design point [41]. Other sources of embarrassment may stem from perceived absurdity of controllers; Deterding notes that "[n]ovel play forms and unconventional instantiations therefore run higher risks of being perceived as improper or strange," due to a lack of institutionalized or conventional framing. To design for safe play is to provide players with means of mitigating feelings of performance unease or impropriety, which can be achieved through one or more of a number of different methods.

Safety in Game And Controller Design

Engendering sensations of safety in the design of games may be achieved through a variety of means, but must address the same set of player concerns: that actions within the play-space may shape judgments outside of it; that engaging in play at all is childish, inappropriate, and embarrassing [39]; that other players' backgrounds may lead to an irreconcilable play disparity in collaborative settings [41]; or that other players in the play-space may buy into the game's artifice to disparate extents [36, 34].

The novelty of alternative controllers acts as both support and detriment to players' perceptions of safety. Game controllers may cause feelings of unease in players not accustomed to skillfully interacting with traditional controls. Blomberg [27] describes the difficulty experienced by players new to a controller. Experiencing a new controller among others who are also unfamiliar with it (caused by the uniqueness and novelty that can be designed into alternative controllers) may help to ease the social pressures that cause this friction. Voida and Greenberg [40] offer a contrasting view of this unease, proposing collocated console gaming space as a place where gamers of different skill levels may interact safely. Though multiplayer spaces may put pressures on novice players, they also may support feelings of safety depending on the individuals in the space. Additionally, controllers that are unfamiliar to all individuals in the play-space (which is true of most alternative controllers) may provide a "leveling" effect, wherein no player has more skill or experience with the control scheme than any other.

While novelty is particularly relevant within the alternative controls space, it is by no means the only method of promoting player perceptions of safety, nor is skill-based unease the only potential cause of social risk during play. Deterding's Goffmanian account of alibis for adult play center on frames that are used by adults in various circumstances to reduce the potential identity threats posed by play [42]. Thus, to create a space within which adults may feel safe playing, designers must incorporate supports for framing play within games and controllers. Excuses for play described in Deterding's work offer a blueprint for keying play that are accepted by adult players and can be supported through controller design. Those most relevant to controller design include mapping to conventional or institutionalized frames of play (thus reducing the distance of play activities from "normal" behavior), or keyings that transform play into an acceptable activity (allowing for alibi generation through actions such as "mock performing, artificially exaggerating, or otherwise ironically keying the action" [42]).

Safety may be supported via a low interaction floor, thus reducing the amount of artifice a player must agree to in order to participate. Additionally, humor is a useful tool for increasing players' sense of safety and decreasing the potential for embarrassment. Players enter the magic circle with the understanding that there is an element of silliness to the play-activity with which they engage, and may set aside reservations when encountering others willing to engage with an amusing premise. Deterding highlights such a joint commitment to frivolity as a means of an in-play alibi: "Few things are quite as involving as other human beings putting their selves on the line" [42]. Designing for collaborative interaction includes design for joint commitment to play, and this component of collaboration can be utilized as a primary or secondary support for player safety.

In Love and Bozdog's *Ola de la Vida* [41], safety is promoted through the custom nature of the controller itself (lowering the barrier to entry for individuals who may not have had extensive experience with traditional game controllers), and the use of a costume to ease uncommon interactions and introduce humor into the play-space. Additionally, *Ola de la Vida* requires the interaction of three players, which further reduces the potential for embarrassment: the collaborating players "may look silly, [but] at least they look silly together" [41]. In *Mad Mixologist*, the humor of spilling drinks and intentionally unskillful action reduces the pressure to perform accurate movements and allows for the generation of humor as performance. *HOT SWAP*'s small controller size, conversely, addresses player safety by asking players to take on less risk int he first place: rather than wearing strange costumes or engaging in large-scale actions, players sit at a table and use small controllers that easily fit in a hand, in a space more closely mapped to the existing play-frame of "video game." Any of these techniques, or combinations thereof, or additional methods of either reducing social risk entirely or otherwise allowing for its framing as more legitimate adult action, can serve to support feelings of social safety.

3.2.2 Social Spaces

Whether described as a magic circle [36, 34, 43], a framed activity nested within reality [37], or an activity with porous boundaries that is constructed and negotiated by players [44], play can be understood as separated from other human activity. The creation of a bounded social space in which playful interaction may occur is the next step in supporting collaborative play. Boundaries, even porous ones, allow for the creation of a world "set apart" from the ordinary that enables players to take on new social roles. Applied to controller design, *Social Spaces* covers controllers' support of either roles in gameplay or the delineation of the play-area as a distinct physical space.

With the artifice of play, players are able to "take on" new roles (outside the realm of the ordinary) endowed upon them by the game and its rules. The play-space is "set apart" in time and space, and rules and events within the play-space are at least somewhat distinct from rules and events outside it. The magic circle allows for the transformation of existing relationships and the generation of new roles and relationships; the magic circle is a key component of play, and thus can be leveraged in service of collaboration within a play activity. In designing collaborative alternative controllers (and the games that use them), it is vital to consider how the physical affordances of the controller can serve to strengthen or weaken the boundaries of the play-world, and how the controller may give rise to patterns of collaboration within it. Salen and Zimmerman propose that players take on roles as part of the social artifice of games [34]; these roles may, and typically do, shift and evolve during play. The creation of a bounded social space in which playful interaction may occur is the next step in supporting collaborative play.

Social Spaces in Game and Controller Design

To some extent, social spaces are created by the very existence of a play-activity, which is central to understanding the magic circle as a broader play phenomenon. However, it is possible to strengthen the role of the social space in the player-experience and thus allow players to "step into" the roles which a game or playful experience asks of them. Engaging with these roles is the next step towards engaging collaboratively. Game and controller design may be aimed towards the end of imbuing players with roles to play — whether they be "player-as-interactor" with specific tasks but little engagement with a game fiction or "player-as-character" where players' tasks are deeply intertwined with the game's artifice.

Creating roles for players to "take on" can be done within-game, and does not need to rely on controllers. This is often done in a game-world and relies upon players identifying with an avatar or some other extension of themselves. These roles may be explicit ("the player is an explorer on an unknown planet attempting to survive among dangerous megafauna"), or implicit ("the player is one of several members of a team and must eliminate other players before their own team is eliminated"), but all imbue the player with a goal, a key portion of many definitions of games themselves. Digital games may achieve this in virtual space using compelling narratives, character creation, or other introductions to the game-world. An advantage of games within more substantial physical areas (including a number of games that use large, highly visible, or wearable controllers, or games whose play-spaces are decorated thematically) is that they may leverage additional components to promote perceptions of space-as-play-space.

Controllers provide an additional means of imbuing roles on players beyond what is possible with game mechanics. Highly visible or wearable controllers may delineate the players as part of a play-world, and further act as means of setting roles upon players. Wearable controllers (such as those in Isbister et al.'s *Hotaru* [45]) act as a particularly clear example of such a phenomenon. Roles are quite literally "put on" by the players: one is either a "gauntlet player" or a "tank player" and must act in accordance with their role to successfully complete game goals [45]. In non-wearable contexts, the influence of the controller on game-space roles is somewhat less literal, but still present. In v21's *Punch the Custard*, players take on the role of "custard-puncher" within the game space, a role which depends directly on action being taken upon the game controller [46]. The sharing of information or physical resources, or reduction in one or both player's capabilities (and subsequent reliance on another player) may be used to increase players' trust in one another (as in *You Better Eat To Survive* [47]) or imbue players with the play-role of "teammates." Teammate roles may also be created by simply tying both players' actions to an outcome. In cooperative games where players succeed or fail as a unit, players assume joint responsibility for the outcome. The arrangement of controls in a setting can additionally serve to create a social space, creating a physical boundary to the nonphysical magic circle, and the inclusion of large controllers (such as Flanagan's *[giantJoystick]* [48]) also serve as means of creating an easily-perceived play space within which players can interact.

Key elements of designing for social space include considerations of how both the physical game space and the controllers (which can create game-space themselves if they are sufficiently large) serve to support players' separation from everyday life and their taking on of additional roles beyond themselves. Simple ways of achieving this included team-based controller designs and mechanics, which can add "teammate" roles to players, and created physical environments in which a game is played to make the boundaries of the play-space visible. Additional means of imbuing roles can include segmenting information and resource access to give each player a designated role and the use of wearable controllers to make a player's position as player and role within the game-world perceptible to an outside spectator. Regardless of which social spaces strategies are chosen, the design of controls that imbue players with additional roles and responsibilities can support collaboration within the magic circle of play.

3.2.3 Interreliance

Interreliance, the innermost theme, translates nearly directly from digital and analog games, and refers to design choices that require players to share responsibility for success. The core precept underlying this theme indicates that players must assume some joint responsibilities for various outcomes within the game, and there are a number of means by which interreliance among players may be promoted. Cooperative settings make for a simple illustration of this idea, in which players work together and either succeed or fail as a unit (as they do in basketball or *Overcooked* [49]. Interreliance is also present in a number of competitive game settings, including games in which players create temporarily alliances to further their own goals or team-based games.

Interreliance, like social spaces, may be promoted entirely in the absence of unique or visible controls. However, the game design practices that support interreliance in traditionally-controlled digital games or analog games may be amplified by controller affordances. Interreliance may be achieved via shared control of a single avatar or output, asymmetrical and complementary controls or abilities, or the limitation of a single player's capabilities to less than what is required to successfully interact with an experience. Rocha et al.'s work on design patterns promoting collaboration [50] includes two patterns directly related to interreliance: *shared goals*, where players work together towards a singular, common goal, and *complementarity*, which refers to designs in which players are given complementary roles and abilities and must coordinate actions. These patterns were further studied by Seif El-Nasr et al. in their investigation of design patterns to support collaboration present in commercial games [51]. Harris and Hancock additionally explore the notion of "asymmetry" with their work on *Beam Me Round, Scotty!, 2*. The authors highlight asymmetry in play as a potential driver of players' "perceptions of connectedness, social engagement, immersion, and comfort with a game's controls"[52] and propose actionable design principles that may support such interactions.

Interreliance in Game and Controller Design

Cooperative games that use traditional controllers such as *Overcooked* [49] and *Keep Talking and Nobody Explodes* [53] demand players' reliance on one another for in-game success by providing goals that cannot be achieved with the abilities available to a singular player. From a design perspective, this means crafting abilities and information sets for players that are a subset of the entire ability or information suite that is required to complete the game.

The splitting or sectioning of player abilities and information can be extended to the design of controllers for interreliance. A controller may enforce interreliance if it is split into multiple parts which constitute a shared resource pool among players (as in Gyory et. al.'s *HOT SWAP: All Hands On Deck* [54]) or enforces asymmetrical or complementary player abilities (as in Isbister et al.'s *Hotaru*[45]). Alternative controllers may also be designed for multiple users, as seen in *Ola de la Vida* [41]; such a controller places the onus of success or failure on multiple players as a single unit. Shared control of a jointly-created outcome is a straightforward means of designing for interreliance, and multi-user controllers allowed outside of the conventional control space allows for such designs to be realized.

3.3 A Taxonomy for Collaborative Controllers

Drawing upon these themes, I propose the following taxonomy for describing and positioning collaborative controllers and related artifacts in relation to the field more broadly.

For each of the three themes for collaborative controllers, I propose a series of descriptors representing the means by which alternative controllers can and do fulfill the theme. Classifying artifacts in this way allows for the conceptualization of works' shared or disparate properties in alignment with the three themes, thus opening the possibility of comparing multiple disparate artifacts.

3.3.1 Safety

Means to approaching *safety* in controller design can be categorized as one or more of the following approaches:

- Humorous Controller and/or Premise
- Low Interaction Floor
- Inclusion of Multiple Players
- Small or Similar to Accepted Controllers

Games that include elements of humor in their premises and/or controllers offer players the opportunity to key their play ironically or lightheartedly, engaging without a great deal of earnesty. Deterding presents humor as one method of generating an alibi for play. Rather than embarrassment, which Deterding describes as an "*un*intentional breach of normative expectations," humor can be read as "a benign *intentional* breach of normative expectations (McGraw & Warren, 2010)" [42]. In settings grounded in humor, players can "make a point of mock performing, artificially exaggerating, or otherwise ironically keying the action" [42]: the players, along with the audience, are in on the joke.

Experiences may also make use of a low interaction floor to allow players to interact without requiring a large amount of divergence from everyday activities. Players may engage with these control setups by standing, walking, sitting, or using a mobile phone. Such design allows for interactors to engage in play while retaining the potential for play-alibis or reducing the risk of being seen performing unusual or childish actions [39].

The inclusion of multiple players, which can, in the vast majority of cases, be considered a requirement for collaborative games, is an additional means of providing players with a feeling of safety. The addition of one or more other people int he play-space willing to take on unusual or potentially embarrassing activity offers players the opportunity the shielding of a group: “although [players] may look silly, at least they look silly together” [41].

Finally, a straightforward means of creating alternative controllers that present less social risk to players is designing controllers’ size and form to be similar to those of existing traditional controllers. Such designs offer a form of play that is similar in nature to other, accepted forms of play (such as play with a console controller or a PC keyboard).

3.3.2 Social Spaces

Means of approaching social spaces can be classified as utilizing one or more approaches that are divided by where the controller (and its contribution to the creation of a social space) is located in relation to the player(s):

- Held or Manipulated by Player(s)
- Worn by Player(s)
- Surrounding Player(s)

Controllers that are held or otherwise manipulated by players utilize an approach to social spaces most like traditional game controllers: by holding, pressing, or standing on the controller, the player is able to be identified as an interactor. Alternative controls, however, offer two additional means of designing physical affordances that support the visibility and role of the social space during play. These approaches include controllers that are wearable and worn by one or more players, serving as costumes that allow players to take on both the role of “player” as well as the corresponding in-game role. Further, many venues in which alternative-control games may be installed allow for greater creative control over the space in which players interact with a game. Approaches that incorporate the design of the space in which play occurs may make use of props, boundaries, or other decorative or functional elements of the space to make the nature and boundaries of the play-space visible.

3.3.3 Interreliance

Means of approaching interreliance can be categorized into one of four groups, based upon whether players have access to the same (*symmetrical*) or complementary (*asymmetrical*) sets of controls and in-game abilities, and whether players' controller inputs are *shared* or *independent*. In symmetrically-controlled games, players have access to identical or nearly-identical inputs and abilities in play. In asymmetrical schemes, players share only responsibility for outcome, but share no other control inputs or outputs. Shared controllers are single control inputs that are used by both players, and can be used to describe games in which players share joint responsibility for the majority of input devices. Independent controllers are those in which players control separate input objects.

3.4 Describing Alternative Control Artifacts using the Three Themes

These themes and taxonomic classification techniques allow for the description of alternative-control games according to the three themes presented in this chapter. I have selected a small number of these artifacts to discuss below in greater detail.

Hotaru: The Lightning Bug Game

Isbister and Abe's *Hotaru: The Lightning Bug Game* is a two-player game that makes use of complementary player abilities and wearable controllers that additionally serve as player costumes [45, 55, 14] Players take on the role of lightning bugs in a fantasy world, working to collect and shoot lightning using one of two wearable controllers, a gauntlet and a backpack, as well as sensor-enabled gloves. Players must hold hands and work together

Figure 3.2: *Hotaru* gameplay, from Isbister et al., 2018 [43].

Safety	Social Spaces	Interreliance
Multiple Players	Worn by Player(s)	Asymmetrical-Independent

Figure 3.3: Taxonomic classification of *Hotaru*.

to collect and disperse energy at a cloud-covered ceiling to complete the game. Spectators are often present, and the wearable controls include illuminated elements that make them highly visible in dark spaces [56, 43].

While the performative nature of *Hotaru* may limit its player pool to those comfortable in engaging in public performance, the game still provides a number of design elements that help even more performative players feel safe in their interactions. The first of these is the presence and physical proximity of the other player. Though controllers designed for collaboration are necessarily used by multiple players, *Hotaru*'s emphasis on physical closeness via hand-holding ensures that players have a partner in performance at all times during play. Isbister and Abe note that within play, the costume-based nature of the controllers allows for social exploration, improvisation, and "nuanced negotiation of social relationship" [43], supporting a small circle of safety for the two players.

Isbister is a key proponent of approaching alternative-control and social games from the perspective of designing for a magic circle. *Hotaru* offers a direct reflection of this principle in practice. Isbister cites proxemics and and the costume-based controllers as primary contributors to roles defined within the magic circle of the game, and on players' interactions with one another. Using costumes, players literally "put on" distinct in-game roles. The wearable nature of the controls and performative nature of the experience further creates a social space in which players are visually "set apart" from the rest of the darkened space.

Hotaru additionally provides an excellent example of complementary asymmetrical abilities driving interreliance in gameplay. In addition to players holding hands for the duration of the experience (which creates a joint responsibility for pair location), players must rely on one another to complete their roles towards the duo's success. The player wearing the backpack must collect energy for the player wearing the gauntlet to use, and the player wearing the gauntlet must use that energy in service of the game's goal; neither player may complete the objective without the aid of the other, driving a tight interreliance that players must engage with if they wish to succeed.

Ola de la Vida

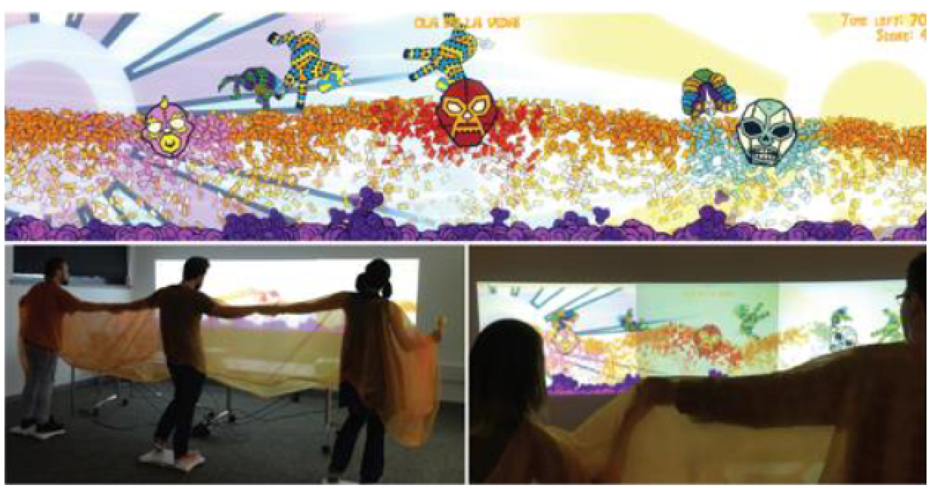

Figure 3.4: *Ola de la Vida* gameplay, from Love and Bozdog, 2018 [57].

Safety	Social Spaces	Interreliance
Multiple Players	Worn by Player(s) Surrounding Player(s)	Asymmetrical-Shared

Figure 3.5: Taxonomic classification of *Ola de la Vida*.

Love and Bozdog's *Ola de la Vida* is a three-player game designed for use in social contexts such as bars, social gatherings, and "play parties," defined by the authors as events that are "designed around a curated collection of games or playful artifacts, either digital, physical or often times a mixture of both, which celebrate co-located social play" [57]. Players don a single poncho with three head-holes, and hold hands with one another; the players on each end hold conductive maracas in their free hands. Each player stands on a Wii Balance Board, and players collaborate to move an on-screen wave that propels small piñata-creatures from one end of the screen to the other. *Ola de la Vida* was explicitly designed for "play party" settings in which individuals, often game enthusiasts, gather at public social gatherings to engage with a number of games [57].

The setting in which *Ola de la Vida* is played is a crucial component of its design and its inclusion of considerations of player safety. The game's designers describe such events as "ecologies of participation"[58] in which "attendees can interact to a level with which they are comfortable"[57]. For Love and Bozdog, the play party itself serves as a safe space for play, within which other modes of play may emerge. The designers describe the creation of a "positive performance space" within the larger safe space, in which spectators may learn about the game from watching before playing. Within the poncho, individuals' actions are less discernible to an observer, providing coverage for players who may be embarrassed to interact when not offered the same visual protection. Furthermore, Love and Bozdog highlight the *Ola de la Vida* control costume's novelty as both a means of creating a "level playing field" for players with varying degrees of comfort with traditional controllers, and a means of promoting "a sense of togetherness and camaraderie" among players [41].

In *Ola de la Vida*, as in *Hotaru*, the wearable nature of the controller itself plays a substantial role in the creation of social spaces among players, and among the larger player-and-audience play community. The game's designers note the ritualization of entry into gameplay as a contributing factor to the experience: "The staged introduction to the game (putting on the poncho, stepping on the pedestal, taking one another's hands etc.) creates an interaction structure for the game as a social object" [57]. The shared nature of the wearable contributes to players' sense of camaraderie, and the continual transfer of play responsibility among players endows players with individualized and renegotiable roles and responsibilities within a play session. The nature of the game is such that the leftmost player takes first responsibility for guiding piñatas onto the "wave of life." Once the piñatas reach the area managed by the middle player, they become the middle player's responsibility, and so on and so forth. Thus, players' actions are directly shaped by their position in the poncho, and taking responsibility for one "segment" of the wave becomes central to their activities during play.

Such continuous negotiation (and renegotiation) of responsibilities illustrates the fundamentally interreliant nature of *Ola de la Vida*. Beyond merely sharing a costume and succeeding or failing as a group, players share actions and responsibilities within the larger three-person play-group due to the requirements of the game. Primary contributors to this reliance include the fact that players must hold hands for the duration of the play session and the transfer of responsibility for the wave "down the line" as players collaborate to move piñatas from start to end. Players "rely on one another physically and digitally in order to achieve the goals of the game"[57]. The designers highlight the role of the individual in the communal activity, noting that the leftmost player may "hold back" newly-appearing piñatas in order to keep the workloads of the other two players manageable [57]. In this way, players become interreliant in physical space (it is impossible to move without moving another player) but also interreliant within the game itself.

HOT SWAP: All Hands On Deck

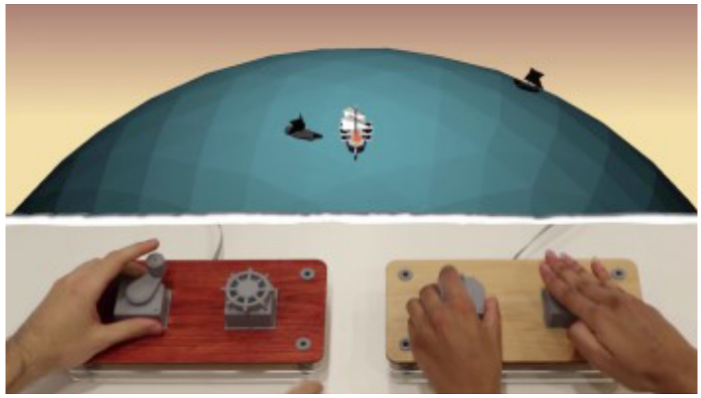

Figure 3.6: Controller and gameplay images from *HOT SWAP*, from Gyory et al., 2019 [54].

Safety	Social Spaces	Interreliance
Multiple Players Small/Similar to Traditional Controls	Held by Player(s)	Asymmetrical-Independent

Figure 3.7: Taxonomic classification of *HOT SWAP*.

HOT SWAP: All Hands On Deck, winner of the 2019 alt.ctrl.GDC showcase, features two player consoles and interchangeable controller attachments, a pool of which both players must share to survive in-game for as long as possible [54, 59]. Players are responsible for driving and managing a virtual sailing ship, which requires steering, sail manipulation, defense from enemies, and emergency reactions (including putting out fires). Each player uses a controller with slots for two "hot-swappable" controls that each address one of these needs; there are a total of five of these controls, and the pool of controls is shared between the two players. Players plug these controls into their controller slots, and manipulate them to keep their virtual ship afloat.

The appearance of *HOT SWAP*'s controllers and the gradually growing intensity of gameplay provide players with a mean of interaction that is visually similar to more conventional forms of play (such as play with console controllers). When deciding to play the game, players only must sit at a table in front on a controller, and are not required to take part in actions that look "out of place" in public settings such as wearing costumes or making large, unusual body movements. While this design choice makes the play-space potentially less discernible to an outside observer, the non-intrusive nature of the control and game setup reduces the social risks of taking part in play; as play goes on, players may become louder or otherwise more visible in their play, but the extent to which this occurs is up to the player.

Owing to its smaller controller size, *HOT SWAP*'s creation of social spaces and the negotiation of player roles within play is substantially different from the first two artifacts discussed here. The play-space is substantially less visible in *HOT SWAP* than in *Hotaru* or *Ola de la Vida*; however, the game's requirements of its players and shared resource pool encourage players to develop a shared strategy over the course of a play-session. Players' use of the various control mechanisms encourages a consistent renegotiation of roles. A player, by taking and using a given control component, assumes responsibility for handling any in-game tasks related to that component.

Rather than using complementary abilities to create interreliance between players, *HOT SWAP* utilizes a shared control resource pool and limitations on individual players' influence to drive player interreliance. Players must react to a number of situations simultaneously, but only four controls (two for each player) may be manipulated at any time. Thus, players must not only share available control resources, but also must trust that their partner will handle their assumed responsibilities and share control components when necessary.

Nintendo Labo Vehicle Kit

Though alternative controllers may be primarily found in festival and independent games spaces, various games peripherals have been released by larger players in the games industry over the years. Nintendo's 2018 Labo project, which enables the construction of playful peripherals from cardboard to work with the company's Switch console controllers, sup-

Figure 3.8: A Nintendo Labo *Vehicle Kit* promotional image, showing the game's constructable cardboard peripherals [60].

Safety	Social Spaces	Interreliance
Multiple Players* (optional) Small/Similar to Traditional Controls	Held by Player(s)	Asymmetrical-Independent

Figure 3.9: Taxonomic classification of *Vehicle Kit*.

ports a recent endeavor into collaborative alternative controls with its *Vehicle Kit* game and peripheral bundle [60]. The bundle includes five constructable cardboard peripherals (three steering devices, a foot pedal, and a "spray canister") as well as cardboard "keys. " These keys enable use of the Switch's Joy-Con controllers in each peripheral and also allow for control by affixing keys to household objects. The game offers an "Adventure Mode" with a co-op option that allows two players using two of the game's peripherals to collaborate to achieve in-game goals [61, 62]. Players can take on the role of pilot or driver of an airplane, car, or submarine, while their partners take on the role of a ride-along "gunner" who can assist with clearing obstacles; players may switch roles during play. Switch and Labo play often occurs in players' homes, so players' social safety is not as immediate a concern as it would be in more public party or festival settings, where several of the previously discussed works have been installed. However, physical features of the controllers for Vehicle Kit and other Labo releases still may contribute to player social safety. The Labo project's DIY aesthetic, supported by the materials used (cardboard) and the "build-it-yourself" nature of the controllers (which are shipped as flat perforated sheets that must be assembled), are reminiscent of childhood play [63]. While such “childish” play may create feelings of unease or embarassment in players, it is also possible that shared use of the controllers marks a shared buy-in to the artifice of the play-experience, and thus an assurance that other players in the space are willing to engage in potentially silly play too.

The cardboard peripherals offered by the Labo Vehicle Kit are significantly larger than the Switch Joy-Con controllers they are built to contain, and substantially larger than handheld gamepads as well, making them much more visible designations of players as players of a game. Furthermore, the controllers included in the kit are specialized, serving one or two purposes in-game (dependent on which vehicle is being used). This allows for the controllers themselves to endow players with roles inside the magic circle; players become a “driver,” a “pilot,” a “gunner,” or a “pedal controller” based upon the controllers they are using. This is similar to the role-based effects of *Hotaru*’s wearable asymmetric controllers, in which the interface players use are directly related to their roles in-game.

Interreliance in *Vehicle Kit*’s Adventure Mode is optional, which sets it apart from the other artifacts highlighted here. Missions may be completed by a single player, and the inclusion of a second player can aid in completion but is not necessary. The game cannot therefore be considered to be truly interreliant, because the second player is not required. The controllers’ relationships with one another during multiplayer mode is, however, worth discussing. Controllers for *Vehicle Kit* demonstrate flexible complementarity. Controllers may serve two or more purposes (steering, aiming), and their uses may be renegotiated during play; switching positions and vehicles requires a coordinated button-press from both players. Regardless of vehicle or players’ roles, players’ controllers remain tied to fundamentally interdependent dynamics; actions must still be coordinated, and control of the vehicle itself may be distributed between both players as seen in The Nintendo Power Couple’s YouTube video describing their experience playing with *Vehicle Kit* [62]. Despite the lack of requirement for a second player, *Vehicle Kit*’s controllers nevertheless display asymmetry and shared control that line up closely with games that do require interreliance.

Mad Mixologist

Fig. 1. Players (B) receive the others' viewpoint as well as instructions through an augmented reality headset. The video that P1 (red headset) sees is shown in A, and P2's (purple) view is shown in C. The featured game is sampled from the Unmatched group, where the bell colors do not match the nearest headsets.

Figure 3.10: *Mad Mixologist* setup and player views, from Grasse et al., 2021 [64].

Safety	Social Spaces	Interreliance
Multiple Players Humor	Held by Player(s) Worn by Player(s) Surrounding Player(s)	Symmetrical-Independent

Figure 3.11: Taxonomic classification of *Mad Mixologist*.

Mad Mixologist is a mixed-reality collaborative game where players wear virtual reality headsets that display the perspective of the other player [64]. Players collaborate to mix a drink in real space while looking at themselves from the other player's perspective. The game, designed to promote collaborative tangible interaction, alternates instruction steps between players: one player is shown odd-numbered steps, and one is shown the even-numbered steps. Between steps, players ring bells assigned to each individual to progress. Players must work together and share information (and coordinate the direction of their head-mounted cameras) to successfully complete the task at hand.

Mad Mixologist relies on humor and absurdity to drive a sense of social safety. There is great potential for embarrassment when players must both don augmented-reality headsets and participate in an activity in which they cannot perform an everyday action with the usual amount of skill. *Mad Mixologist* addresses this potential by leveraging the amusing results of less-skilled interaction with fluids. Rather than punishing players for making mistakes in pouring or mixing, the game allows for humor to come from failure in-game.

Even if players struggle to correctly pour liquids, a mistake can allow for players to laugh at themselves and the absurdity of the situation.

The social space of the *Mad Mixologist* game is driven primarily by two components. The first, the augmented reality headsets worn by the players, endows the players with in-game roles, which are furthered by the players' use of the headsets to view game instructions. Instructions are displayed via an interface superimposed over the player's camera feed. Players alternate roles of instruction-giver and instruction-receiver based upon the information given during each step. Further, the space itself, visible through players' headsets and to spectators, defines its own magic circle. Grasse et al. describe *Mad Mixologist* in terms of personal and shared spaces, with players interacting with objects in both [64].

Interreliance in *Mad Mixologist*, beyond the players' shared responsibility for the resulting beverage, relies heavily on asymmetrical gameplay and information. Players must rely on one another to receive step-by-step instructions. The player who does not see an instruction during any given step is instead offered the suggestion to ask the other player how they can help. Players additionally share responsibility for the shared space in which much of the gameplay occurs. Furthermore, *Mad Mixologist* requires players to literally see their actions from the other player's perspective. In order to see what is happening, players must attune their head movements to their partner's visual needs during the game.

The variety present in even the small number of alternative controllers whose designs have been published in academic outlets highlights the multiplicity of approaches that may be taken to addressing themes of safety, social spaces, and interreliance. Each artifact highlighted here presents a unique combination of physical and digital features that address needs for collaborative play. A key consideration to be made here is that the documented controller- and mechanic-based strategies for addressing each theme, should be considered theoretical; a central part of the work of this thesis is the pairing of physical affordances designed for each theme to data about sense-making during play. This will be achieved by the use of creative sense-making analysis of play with each of the artifacts developed for this thesis; an overview of the creative sense-making framework is presented in the following section.

3.5 Creative Sense-Making

Davis et al.'s creative sense-making framework extends participatory sense-making into the creative domain and allows for the representation of dyadic embodied interaction as a series of states as interactors shift between fluid, clamped interaction and temporary disconnections from the task at hand to refine their mental models. Play with alternative controllers is often inherently improvisational in nature, as players use their mental models of a game and its controllers to craft strategies for achieving their goals during play. It is ideal for understanding embodied collaborative play, owing to its design for describing embodied creative interaction, its ability to quantify interaction dynamics in such settings, and its consideration of embodied and social sense-making processes. Creative sense-making has roots in De Jaegher and Di Paolo's participatory sense-making framework, which takes both embodied action and social interaction to be key components of sense-making in social situations. While creative sense-making differs from participatory sense-making in both its approach to describing social cognition and the scope of its intended use, it is worth briefly discussing participatory sense-making as it relates to embodied collaboration, and embodied collaborative play more specifically.

Participatory sense-making, proposed as an extension of the enactive paradigm into social interaction by De Jaegher and Di Paolo in 2007 [19], proposes that interaction itself is a key component of social cognition. Rejecting the idea of social interaction as a process by which one individual attempts to "figure out" the intentions and meanings of another, De Jaegher and Di Paolo contend that there is mutual influence between the coordination of interactors and the interaction itself. The authors define participatory sense-making as "the coordination of intentional activity in interaction, whereby individual sense-making processes are affected and new domains of social sense-making can be generated that were not available to each individual on her own"[19]. The concept is an extension of the enactive view of the individual as sense-maker into the social domain, and its definition covers a number of important components.

Central to participatory sense-making as an activity is *coordination*, defined by the authors as "the non-accidental correlation between the behaviors of two or more systems that are in sustained coupling, or have been coupled in the past, or have been coupled to another, common system" [19]. The activity must also be *intentional* - an agent cannot accidentally or unwillingly participate in the joint sense-making. The process must also involve *interaction*: here, a social interaction is defined as a "regulated coupling" that involves two or more autonomous agents, regulation aimed at aspects of the coupling itself, and the coupling's existence as an "emergent autonomous organization" that does not destroy the autonomy of the interactors.

Participatory sense-making provides two key influences on sense-making processes, according to De Jaegher and Di Paolo. First, it influences individual sense-making processes by affecting how the involved agents build meaning in their world. Secondly, it offers "new domains of social sense-making" that go beyond what is available to the individual, and thus opens up and additional dimension of meaning-making activity. Participatory sense-making also forms a cornerstone of Fuchs and De Jaegher's work on enactive intersubjectivity, which presents social understanding an an "ongoing, dynamical process of participatory sense-making and mutual incorporation" that includes an emphasis on the embodiment and bodily actions of interactors within the space of a social interaction [65, 66]. It is thus appropriate to understand participatory sense-making as a valid means of understanding social interactions in a variety of spaces, particularly those within embodied contexts.

Creative sense-making, which builds on the participatory sense-making framework, provides a targeted means of quantifying embodied social sense-making and is particularly apt for use in play-based settings. Davis proposes the notion of *creative sense-making* to describe the participatory sense-making processes of interactors engaged in creative or improvisational activity [18]. Following an initial investigation into dyadic pretend play as an activity involving participatory sense-making [67], Davis proposes that sense-making may be quantified by an examination of free energy in the mind: "Sense-making is described in terms of free energy as the process by which free energy is gradually reduced in the brain by experimentally interacting with the environment to gradually increase the accuracy of the agent's internal predictive model"[26]. The resulting enactive descriptions of improvisational processes illustrate processes by which an interacting agent engages in or diverges from a flow-state (similar to that described by Csikszentmihalyi [68]). Divergences occur when the agent has a need to refine its mental model of the ongoing interaction space to increase the model's predictive accuracy and reduce surprise. This may be achieved by a "partial" or "full" *physical unclamp*, in which the agent interacts physically with its environment to collect resources or expand its predictive model, or a "partial" or "full" *perceptual unclamp*, in which the agent works internally to improve its mental model (e.g., thinking).

From the participatory sense-making framework, Davis et al. derive key components of creative sense-making, including participatory sense-making's approach to understanding social cognition as an embodied interaction in which the interaction affects interactors' sense-making processes. Creative sense-making also is substantially narrower in scope, and was originally used for describing open-ended, creative improvisation, rather than the much broader scope of human social cognition which is covered by participatory sense-making. Davis et al.'s conceptualization of improvisational activity as a continuous action alternating or moving between clamped and unclamped cognition is further extended into quantifiable categories and a video analysis tool to simplify coding along this scheme. This tool has been used to analyze and describe interaction dynamics and trajectories in co-creative settings, such as pretend play and collaborative drawing with an intelligent (human or AI) partner [69, 18].

Davis et al.'s application of creative sense-making analysis to collaborative drawing yielded data that allowed for the comparison of human-AI collaborative sketching sessions with human-wizard of Oz collaborative sketching sessions, outlining differences between sense-making activities and creative collaboration in each condition. This use of creative sense-making analysis to support comparisons between conditions is not unlike its application to gameplay with different artifacts. Furthermore, interaction with a new game controller and exploration of its capabilities is a fundamentally improvisational activity not unlike the creative activities described by Davis. While such activity is typically more goal-oriented than abstract drawing or pretend play, two scenarios to which the creative sense-making framework has previously been applied, the exploratory and co-constructed nature of the activity gives rise to similar clamping and unclamping events. Thus, I propose the use of Davis's creative sense-making categories to describe the interaction patterns of individuals engaged in collaborative play with alternative game controllers. This means of describing collaborative embodied play offers a holistic view of player's collaborative processes during play, which can be mapped to physical affordances of the controllers. Such mapping allows for the development of new knowledge about how controller design may relate to the collaborative aspects of play, and thus offer designers insights into crafting controllers to support various patterns of collaboration during their use.

CHAPTER 4
BOUNDARY ARTIFACTS

I developed three boundary artifacts to be used in study sessions to support the collection of creative sense-making data about dyadic interaction with alternative controllers. These artifacts were designed to include physical affordances covering a variety of disparate approaches to address the three themes for collaborative controllers, which can be visualized by noting the shared and disparate classifications of each in figure Figure 4.1. Controller and gameplay design and implementation for each artifact is described in this chapter.

	Safety	Social Spaces	Interreliance
Haber Dasher	Multiple Players Humor	Worn by Player(s) Surrounding Player(s)	Symmetrical-Shared
Trip	Multiple Players Humor	Held by Player(s) Surrounding Player(s)	Asymmetrical-Independent
Sound Happening	Multiple Players Low Interaction Floor	Held by Player(s) Surrounding Player(s)	Symmetrical-Independent

Figure 4.1: The three boundary artifacts developed for this thesis, described using the three themes taxonomy.

4.1 *Haber Dasher*

Haber Dasher is a game in which two players share and tilt a large bowler hat to control an on-screen character. The hat controller, which is eight feet wide and worn by two players, was designed to explore the sense-making patterns of players engaged with a shared, wearable, and highly visible controller. The game's fiction supports awkward movement: the players' avatar is a human-shaped suit piloted by an alien attempting to blend in with human society. Players must coordinate their motions while wearing the hat in order to complete a series of objectives.

4.1.1 Controller

The controller for *Haber Dasher* is a large bowler hat that is worn by two players and measures approximately 8 feet in width, 4 feet in depth, and 3 feet in height. The base of the hat is solid, with two padded hemispherical indentations that sit atop players' heads (shown in Figure 4.2 and Figure 4.3). The hat was suspended from scaffolding during studies to reduce strain on players' necks and increase stability of the hat.

Figure 4.2: The *Haber Dasher* hat controller.

Gameplay

In *Haber Dasher*, two players take on the role of an alien named Zorg who is attempting to take over Earth by gaining power among the humans as a businessman. Players are offered clip-on ties as an optional wearable element. Players of *Haber Dasher* stand side by side, roughly 30 inches from one another, and face a large monitor displaying the game. Before the game begins, players stand still for a calibration routine (which calculates an offset vector to account for any height difference between players) and receive instruction

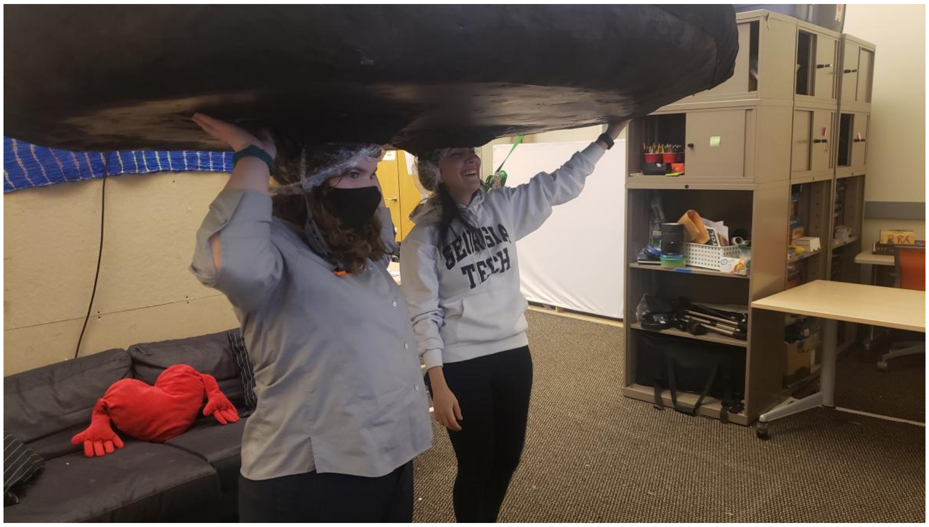

Figure 4.3: Two players interacting with the *Haber Dasher* controller.

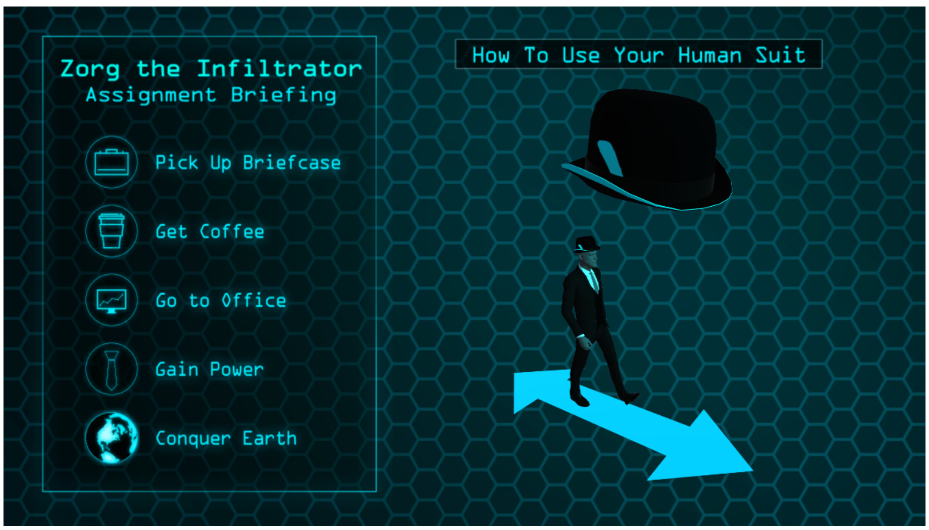

Figure 4.4: *Haber Dasher* briefing screen outlining in-game goals and animated control instructions. The hat and the human suit on the right are animated, showing all four directions of tilt and the resulting directional movement.

detailing how they are to use the hat to control their shared avatar (see Figure 4.4). To complete the game, players engage in three "businessman" activities and aim to complete these tasks as quickly as possible. The tasks are as follows:

- Task 1. Walk to and pick up a briefcase object (by walking into it) near the player character's starting position.

- Task 2. Walk to a coffeeshop farther from the starting position and pick up a coffee object by walking into it.

- Task 3. Complete game by walking to an office building in a different part of the map without spilling the cup of coffee. Should the coffee spill, players will be required to return to task 2.

A number of obstacles, including pedestrians and buildings, exist in the game environment and may slow players' progress. For example, bumping into an aggressive or daydreaming pedestrian slows the player's walking speed and knocks the character back temporarily. If the player avatar is carrying a coffee when he bumps a pedestrian or building, this also causes the coffee to spill and Task 2 must be completed again before Task 3 becomes available. A screenshot of the gameplay is shown in Figure 4.5.

Figure 4.5: *Haber Dasher* gameplay.

Technical Implementation

Embedded within the hat controller is an Android smartphone, which sends accelerometer data via WiFi connection data to a host PC running the game. The Android and PC applications make use of the Easy WiFi Controller Unity Engine asset to send accelerometer data over a network. Built-in functionality within the asset transforms accelerometer values into a two-dimensional vector describing the angle at which the phone has been tilted along its forward/backward and left/right axes.

When this data is received by the host PC, the vector value is applied to the animated motion of the player avatar (as shown in Figure 4.6). The avatar is able to move freely around the game-world, which comprises several simulated city blocks. Boundaries of the game-world, as well as building walls, are enforced using a "bump" control that causes the player character to stumble if he runs into one of these boundaries. Despite the fact that players would occasionally be able to go inside of building models, the dynamics of players attempting to figure their way back out of a building offered fascinating displays of sense-making and activity coordination.

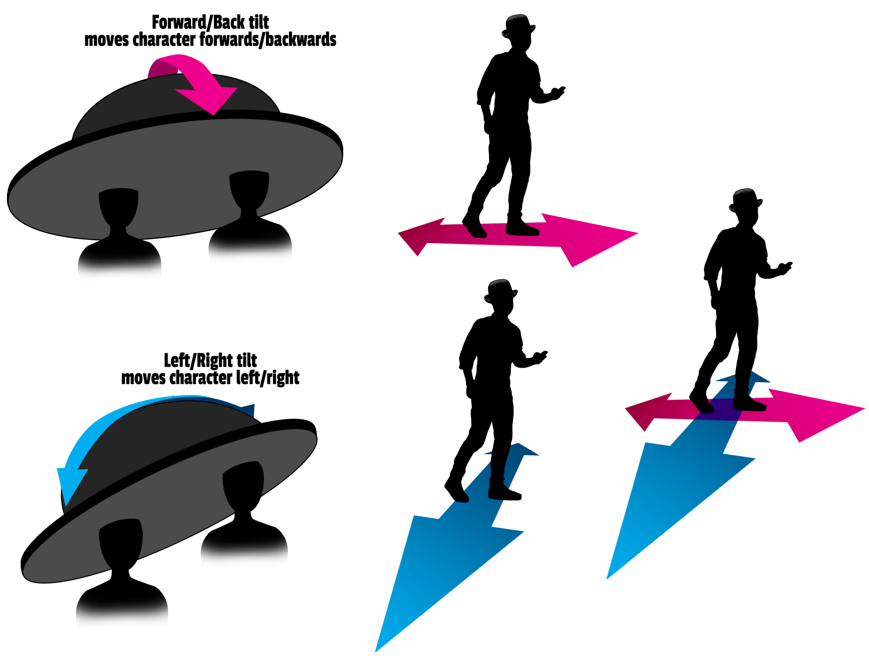

Figure 4.6: The two axes of control in *Haber Dasher*.

Players must move their avatar into proximity to goal object (a briefcase, a coffee cup, and an office building door). Upon entry into the space immediately surrounding the goal object, the goal is achieved, the next goal is activated on a heads-up display and a minimap, and the player character is shown holding the object (in the case of the briefcase and coffee) or the game ends (in the case of the office).

4.1.2 Design Process And Goals

The driving goal in the design of the *Haber Dasher* was the investigation of sense-making processes of players engaged with a shared, wearable, largely visible controller. Development of the original idea for the controller grew from the intention to utilize a controller that was large enough to mark players as participants in the play-space, and shared control equally between two players.

The hat's large size serves a dual purpose in supporting the three themes for collaborative controllers. At the *safety* level, the size is so big as to be absurd; the controller falls on the "altering perception" end of the safety spectrum, and allows players to laugh at themselves while they interact with a ridiculous object. Further, the hat's size positions it somewhat unusually in terms of *social spaces*; while the hat is wearable, its size makes it as much a play-space as it is a controller.

The hat was designed for the purpose of investigating players' sense-making activities when they share a single, large controller that is too physically large for either individual to control alone. Due to the size and material properties of the hat, it is impossible for one player to use the controller alone. It is additionally impossible for one player to "take over" control, since both players wear the hat simultaneously. *Haber Dasher*'s gameplay further emphasizes the shared nature of the input, extending players' joint responsibility into the game-world, where the two players control a single avatar. *Haber Dasher* can positioned at the "shared" extreme of the interreliance axis.

4.1.3 Collaborative Principles

Haber Dasher relies primarily on the wearable aspect of its controller and the controller's large size to promote collaborative interaction patterns. The hat's wearable nature and large size marks players as interactors and physically defines the boundaries of the play-space, as players remain under the hat for the duration of the play session. Furthermore, the hat's two-player design and rigid design mean that players must coordinate their actions to manipulate the controller.

Safety	Social Spaces	Interreliance
Multiple Players Humor	Worn by Player(s) Surrounding Player(s)	Symmetrical-Shared

Figure 4.7: Taxonomic classification of *Haber Dasher*.

Interreliance via Shared Control

The shared aspect of the *Haber Dasher* controller provides two key supports for interreliance in play: shared inputs and shared outputs. The shared nature and rigidity of the controller mean that if one player moves the hat, the other must (or will be forced to) move with them: it is impossible for players to act independently of one another while playing. The second interreliance support relies both on the controller itself and on the design of the *Haber Dasher* game: the two players share a single hat and drive the actions of a single avatar. Success, failure, and other events in-game are necessarily jointly driven.

Social Spaces via Wearable Controller

Similar to the large poncho worn by players of *Ola De La Vida*, the two-player bowler hat delineates a play-space primarily through its large size and wearable nature. Though players in the *Haber Dasher* studied played the game in a controlled lab environment and not within a broader social context such as a festival or party, its size clearly endows its wearers with a marker that they are participating in something set apart from ordinary life. The wearable aspect of the controller supports this as well; in donning the hat (and optional clip-on ties), players "take on" the role of Zorg and become participants in the play-action. *Haber Dasher* can be placed near the center of the social spaces axis. The hat is simultaneously controller and play-space. Its wearable nature defines roles for the wearers, but its size (and position above and encircling the players) creates a play-space bounded by its brim.

Safety via Novelty and Humor

A primary driver of safety in the *Haber Dasher* play-space is the humorous nature of a gigantic hat, augmented by optional clip-on ties for players, as well as the somewhat unwieldy nature of the control. The controller's form and nonserious nature of the game fiction permit players to engage with the game lightheartedly, and many interactions among players included laughter and jokes about the game and usage of the controller. Additionally, the hat control's novelty means all players began with the same level of familiarity with how the hat was meant to be operated, leading to joint activities of exploring the controller's affordances and outputs and players sharing the process of discovery.

4.1.4 *Haber Dasher* Gamepad Control Version

I developed a second, modified version of *Haber Dasher* developed to utilize two traditional gamepad controllers to investigate potential differences in sense-making processes in players between alternative-control and traditional-control conditions. The gamepad-control version of *Haber Dasher* uses the same input scheme as the hat-control versio, with input values along two axes being translated to movement along two axes. X- and Y-axis values from the left joystick on each controller are averaged to translate two controller inputs into a single avatar control input. The game is otherwise identical to the original version of *Haber Dasher*, with the minor alteration of the briefing scene to reflect the different controller input.

4.2 *Sound Happening*

Sound Happening is an Expressive Machinery Lab project that translates the motion of beach balls within a space to musical output utilizing a webcam mounted above the play space to track the position of the balls in space. Differently-colored balls are mapped to different instrument sounds (e.g., bass, percussion), and motion of these balls into different locations in the play space produces auditory outputs based upon the balls' position [70]. This installation has been exhibited in multiple contexts and has previously been utilized as a design probe to investigate design for parent-child interaction [70].

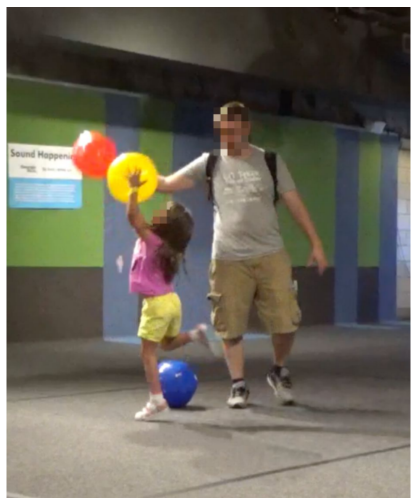

Figure 4.8: A parent and child interacting with *Sound Happening* at the Children's Museum of Pittsburgh, from Long, Guthrie, and Magerko [70].

While not strictly within the games paradigm, the installation offers an open-ended, playful experience that has a number of settings that are useful for investigating collaboration dynamics in a ludic space. This installation was selected for inclusion in this work as a contrast to the other two artifacts, which both include built-in play goals. *Sound Happening* is designed as an exploratory experience, making it an apt candidate for description in terms of users' sense-making activities.

4.2.1 Controls and Technical Implementation

Sound Happening runs as a Max/MSP patch on a Mac Mini, which is mounted inside a pop-up canopy or other similar structure that serves as the play space. Mounted at the top of the play space is a downward-facing webcam that captures the position of colorful beach balls within the space. Three ball colors are tracked at a time, and their areas and position midpoints as read by the webcam are used to drive properties of the system's sonic output. Each colored ball, when present in the play-space, triggers the playing of an instrumental loop; each ball color corresponds to drums, bass, or a synth melody, all of which loop constantly and turn on and off as their corresponding balls enter or exit the play space. Balls' positions in space drive a number of additional sonic properties and effects.

Balls' area within the tracked space reflects the vertical position of the balls in the play space (balls held higher up appear larger to the webcam); this property is used to drive the note density of the corresponding instrumental loop. Loops of three note densities may be played for each instrument: low density, which occurs when balls are on or near the ground; medium density, which occurs when balls are roughly torso height; and high density, which occurs when balls are held up near the webcam, typically over the head.

Balls' position in relation to other balls present in the play-space is used to affect the speed and pitch of the output sound of the system. The average distance between balls in the play-space drives the speed of the instrumental loops. When balls are close together, the loops play quickly at slightly above original speed. When balls are far apart, the loops play more slowly than the original speed. The midpoint of all balls present in the play-space drives a pitch distortion parameter. When the midpoint is near the center of the play-space, the sounds play without distortion; as the midpoint moves towards the edges of the space, a small pitch shift is applied to the output of the system. These relative-position outputs were designed to encourage sense-making activities beyond those of the individual.

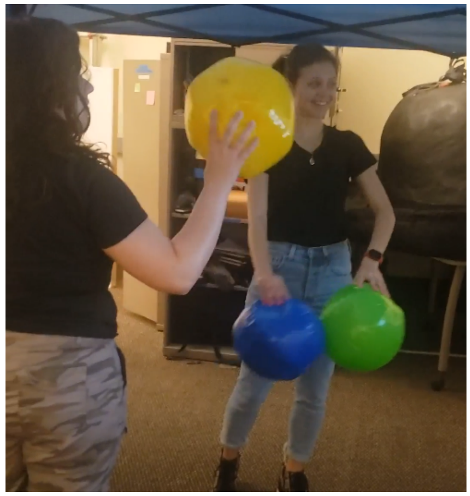

Figure 4.9: Individuals interacting with *Sound Happening* during the preparations for the public study in Atlanta.

4.2.2 Design Process and Goals

The version of *Sound Happening* used for this study was based upon an earlier version of *Sound Happening* designed for adult-child play in museum contexts. This version was modified to add musical complexity to promote exploration. In addition to the existing on/off of instruments and changes to speed and sound based upon ball position, relative ball position and collective ball position within the space were included as additional inputs, controlling properties of the sound that were previously static.

A primary rationale for the inclusion of *Sound Happening* among game artifacts is its lack of a defined goal-state. In contrast to *Haber Dasher* and *Trip*, users of *Sound Happening* are not provided with a goal to work towards, and the installation invites exploratory interaction and "figuring out" how the installation works. The complexity added during the modification process adds additional degrees of complexity and extends the axes of interaction. Interactions with the modified *Sound Happening* system included players exploring the different effects various ball positions had on the overall sound of the system and theorizing about which properties of the balls' position related to which properties of the output.

Sound Happening is the only of the three artifacts developed for this thesis to emphasize safety using a low interaction floor. In contrast to *Trip* and *Haber Dasher*, which use size and humor to promote players' feelings of social safety, *Sound Happening*'s interactions require a great deal less buy-in to artifice. *Sound Happening* lowers the perceived social risk of interactors by reducing, rather than transforming, the social risk involved in interacting.

4.2.3 Collaborative Principles

Safety	Social Spaces	Interreliance
Multiple Players Low Interaction Floor	Held by Player(s) Surrounding Player(s)	Symmetrical-Independent

Figure 4.10: Taxonomic classification of *Sound Happening*.

Safety via low interaction floor

Safety reflects a primary aim of the *Sound Happening* design team, who sought to create an installation that supported playful engagement among children and adults alike. Allowing for a low entry floor (picking up a ball and walking about the space) encourages adult participants to engage with the experience without feeling embarrassed, as the actions performed in interacting with *Sound Happening* are very similar to standard, everyday motions such as standing. The interaction involves moving objects around a space, and does not demand a significant amount of social buy-in, thus reducing the potential for embarrassment in the way other, more involved play settings might [70, 39].

Social spaces via visibility and resource sharing

Social spaces arise within the *Sound Happening* installation in two ways. First, the installation is contained within a pop-up canopy (or another, similar structure) that distinguishes the play-space from the surrounding area. The beach balls used in the installation are large (approximately 14 inches in diameter) and bright, and the amplified audio output makes the installation perceptible from the perspective of a passerby or onlooker.

Holding, throwing, or otherwise interacting with one or more balls is required for participants to take part in the co-creative playful experience. Picking up or being handed a ball immediately endows the interactor with the role of "co-creator,“ which persists for as long as they are actively involved in the motion of balls about the space. The shared nature of resources (balls) in the installation furthers the social aspect within the play-space: players must negotiate their use, exchange, and interaction with resources that must be shared among all interactors.

Interreliance via joint control and Multi-Input Audio Effects

Sound Happening's support of interreliance also draws from two components of its design. Primarily, interreliance is driven by the shared output of the system; regardless of how many balls or interactors are in the space, all inputs control a singular auditory output. Though *Sound Happening* offers interactors a greater deal of independence, there remains a joint responsibility for the audio output of the system. Additionally, the system has been designed to allow for the inclusion of audio effects that occur when participants perform certain coupled actions, such as moving balls into close proximity with one another or moving all balls to the corner or center of the play-space. Such effects require coordination of all ball-holders in the play-space.

4.3 *TRIP: A Cosmic Adventure For Two*

4.3.1 Gameplay

Trip: A Cosmic Adventure for Two is an asymmetrical-control game in which two players take on the roles of astronauts on a spaceship attempting to return to Earth while hallucinating. Players in *Trip* take on one of two roles: the Driver or the Navigator, who share responsibilities and information required to keep the ship intact. Players are separated by

Figure 4.11: A mockup of player controls for *Trip*, with the Driver shown at left and Navigator shown at right.

an opaque screen which prevets them from seeing one another's screens. The ship begins with 100 points of health, and health is deducted for ramming into asteroids and missing timed events during play. The game ends if the ship's health fully depletes.

The Driver controls the motion of the ship by standing on a modified hemispherical balance ball with a mobile phone to be embedded within it. A stationary yoke is available to help the player maintain balance and not fall over. Tilting the balance ball left and right causes the ship to turn in the corresponding direction. The Driver UI displays a small ship icon in the lower right to communicate to the Driver which way and how much they have tilted the balance ball. The Driver is sees models of the levers, buttons, and sliders that must be manipulated by the Navigator to keep the ship running smoothly. This information must be communicated to the Navigator in a timely fashion to prevent damage to the ship. The Driver is not able to see the space in front of the ship, and must receive directional information from the Navigator.

The Navigator operates the ship's Control Panel, which is a panel of 3D-printed buttons, levers, and sliders designed to appear unusual. These must be manipulated within certain periods of time to keep the ship running smoothly. Failure to do so will cause the ship to slow and lose ten points of health, and too many failures will end the game. The Navigator is able to see the space in front of the ship, and a map of the area they are in. They are responsible for conveying this information to the Driver, who steers the ship. The Navigator is not able to see which control panel items must be manipulated, and must rely on the Driver to provide this information.

Figure 4.12: A player interacting with *Trip*'s navigator control panel and display.

4.3.2 Controllers

Navigator Control Panel

The Navigator's controller is a panel of sliders, levers, and buttons that are unusually shaped, and must be manipulated in timed control panel events to keep the players' virtual ship from breaking down. The control panel registers events through two Arduino Unos embedded in the control panel, which connect to the computer running the game via serial cables. The Arduino boards send interaction data to two serial ports on the host PC running the *Trip* game using the Ardity plugin for Unity.

Figure 4.13: A player interacting with *Trip*'s driver controller and interface.

Driver Balance Board

The Driver stands on a hemispherical balance board, which can be tiled to drive the spaceship. The Driver is also given a nonmoving yoke to hold onto in order to aid in balance and reduce physical fatigue during play. Embedded in the balance board is a smartphone running a client app using the same technology as the *Haber Dasher* hat and sending accelerometer data to the *Trip* game over a wi-fi connection. This data is received by the host PC running the *Trip* game and translated into spaceship movement and rotation.

Figure 4.14: A player interacting with *Trip*'s navigator control panel.

4.3.3 Game

Game Fiction

The *Trip* game is displayed across two screens connected to a single host computer running the game. Players receive an audio and textual briefing detailing the situation they are in before play begins (after the Driver's controller is calibrated). The players are two astronauts who have just landed their ship on a planet whose atmosphere causes vivid, intense hallucinations. Furthermore, the Driver is showing signs of vertigo. The ship itself is experiencing a number of mechanical malfunctions, and the two players must navigate their ship back to safety immediately while managing these challenges.

Movement

Trip is organized into 10 levels, each of which includes a path that must be charted through an asteroid field. Players receive points for completing levels. The Navigator views a screen that simulates the "front window" of the ship, and can identify obstacles and directional information. This must be passed to the Driver, who controls the ship's motion using the balance ball controller. The ship is damaged and slowed and points are lost if the ship hits an obstacle. Points are awarded for keeping the ship intact, and an additional point bonus is awarded upon level completion. This bonus is larger the faster the level is completed.

Control Panel Events

Moving the ship through parts of the level during play causes the Driver's screen to display a timer and a 3D model of a lever, button, or slider on the Navigator's control panel. The Navigator must interact with this object within the allotted time, or the ship will slow down for a short time and take damage. If the Navigator interacts with the wrong object, the time remaining for the player to complete the interaction is halved. Rapid completion of control panel events is rewarded with additional points.

Fail State

The ship begins each level with 100 health points. The ship's health slowly regenerates during play if it is less than 100. Health is decreased by 10 points if the ship collides with an asteroid or if players fail to react to a control event in the allotted time. If the players' ship health fully depletes during a level, the game ends. Players are then taken to a leaderboard display, and may select a name or initals to be entered if they scored sufficiently high to be listed on the leaderboard.

4.3.4 Design Process And Goals

The initial design goal that led to the development of *Trip* was the necessity of developing an artifact that achieved *interreliance through asymmetry*. This property was selected as a contrast to *Haber Dasher* and *Sound Happening*, both of which rely heavily on joint control of a singular input system to operate. *Trip* was conceived as a game in which players would find challenge in describing unusual objects to one another. This activity poses a difficult joint sense-making task where both players had to convey and receive information simultaneously.

4.3.5 Collaborative Principles

Safety	Social Spaces	Interreliance
Multiple Players Humor	Held by Player(s) Surrounding Player(s)	Asymmetrical-Independent

Figure 4.15: Taxonomic classification of *Trip*.

Safety via Mutual Involvement and Humor

As with *Haber Dasher*, a primary component of *Trip*'s promotion of player safety is humor. The strangely-shaped objects on the control panel and the difficulty of staying upright on a balance board contribute to a sense of nonseriousness within the play-space. *TRIP* does not require a great deal of earnestness from its players (drivers may describe objects in terms as nonserious they wish, and navigators are only requried to give directional information), and thus allows for lighthearted engagement with limited social risk. Furthermore, *TRIP* draws from the principle of "looking silly together" [41], engaging players two at a time as a team within which individuals know they will not be judged by their partner. The unusual control scheme and necessity for one player to describe strange objects to the other contribute to this effect. TRIP cultivates an atmosphere of humorous interaction, resulting in lighthearted interactions and laughter during play.

Social Spaces via Game Fiction and Controller Space

Trip's fiction and controller layout serve as dual supports for players' roles within the social space of play: the physical game space and the role-based assignments given to each player. The game-space is literally "set apart" from the rest of the space it is in, sitting on a raised platform and sectioned off by dividers. Players must "step up" into their roles at each individual station. The briefing sequence at the beginning of the play session introduces and assigns the roles of Navigator and Driver to players, and sketches out the game's fiction before play begins. These roles are further solidified by the controllers provided to each player; players "take on" the roles of astronauts by virtue of their fictitious predicament as well as their in-game responsibilities.

Interreliance via Asymmetry

Trip relies heavily on its asymmetrical control scheme to drive interreliance between its players. The restriction of information and abilities is amplified by the highly different controllers. The limitation of information available to each player creates a need for the back-and-forth exchange of instructions ("turn left," "pull the blob-shaped lever"), often simultaneously. Neither player can successfully complete the game responsibilities required for success without the input of the other.

CHAPTER 5
CREATIVE SENSE-MAKING ANALYSIS

Four sets of user sessions were conducted to collect video recordings of dyads interacting with each artifact. Three of these sessions used an alternative-control game using the controller designed for the game. For the purposes of comparison with traditional control setups, a fourth series of sessions used the version of *Haber Dasher* modified to utilize dual inputs from traditional controllers. For each study, 15 or more dyads were recruited from the Georgia Tech campus community using sign-up posters at public places on campus and outreach emails to students in introductory "GT 1000" courses. Players were instructed to sign up with a partner whom they already knew, following the same procedure used in Davis' work so that players would not be interacting with strangers and would share existing social familiarity with one another [67]. Video recordings and observer notes were collected from each session. The *Haber Dasher* software tracked gameplay data for each session, including time spent on each task, number of pedestrians bumped, and number of coffees spilled.

5.1 Generation of Creative Sense-Making Curves

Each series of session videos was analyzed by a team of video coders using the Expressive Machinery Lab's creative sense-making video analysis tool, which allows for the recording of creative sense-making state data for each player at a rate of 10 frames per second. For each frame, an individual's sense-making state is coded as a value of -1, -0.5, 0, 0.5, or 1. In this scheme, 0 represents clamped action, positive values represent partial or full physical unclamped states, and negative value represent partial or full perceptual unclamped states.

The iterative coding scheme described by Davis [18] to establish inter-rater reliability. For each artifact, a sample video was coded, divergences in coding were discussed, and the process was repeated until agreement was reached. The resulting creative sense-making state information was used to generate creative trajectory curves by first creating an integral curve using the values for each player (shown in Figure 5.1), then summing the integral curves from both players. The slopes of these curves were used to shade under the curves to delineate the joint sense-making states of the dyad during play as shown in Figure 5.2.

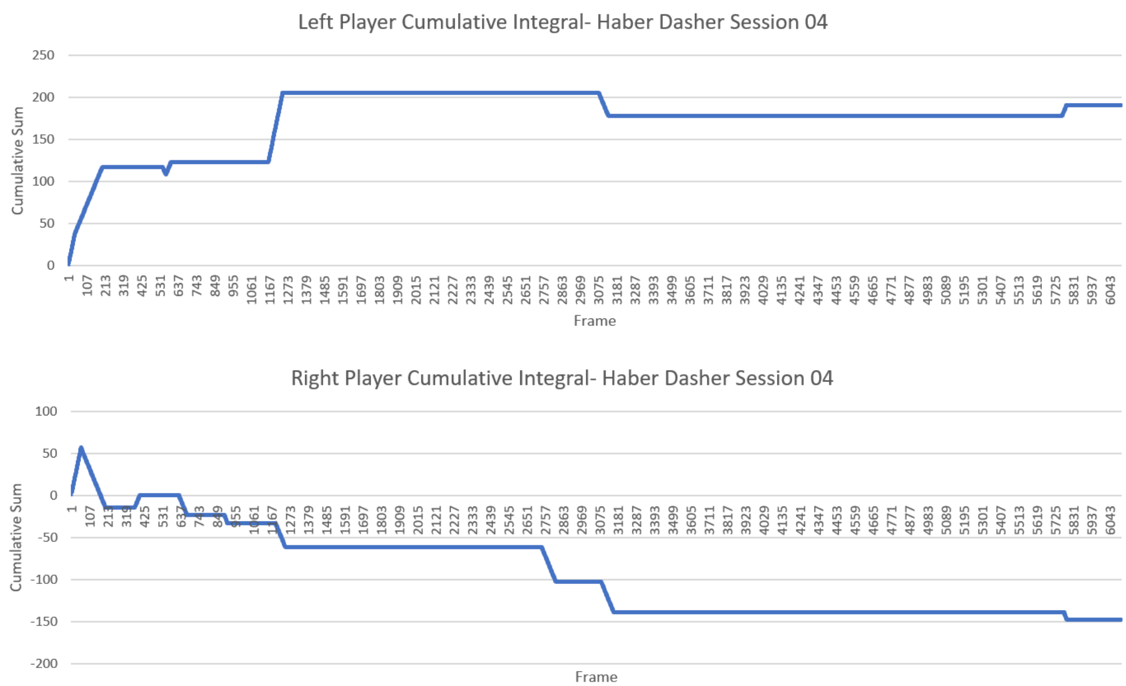

Figure 5.1: Individual sense-making curves from a *Haber Dasher* session.

Using the guidelines set forth by Davis et al. [18, 71] we identified three sense-making states: *mutual exploration*, where players work together to explore the physical capabilities of the controllers; *mutual thinking*, where players are asking questions of one another or otherwise taking in new information about the digital world in which their avatar is moving; and *coupled play*, likened to a flow-state [68], in which both players are engaged physically and skillfully moving the controller to achieve their objectives.

These states may be defined using properties of the joint sense-making creative trajectory curve produced by summing the two players' individual cumulative curves. *Mutual exploration* is characterized as a period in which the slope of the trajectory curve is primar-

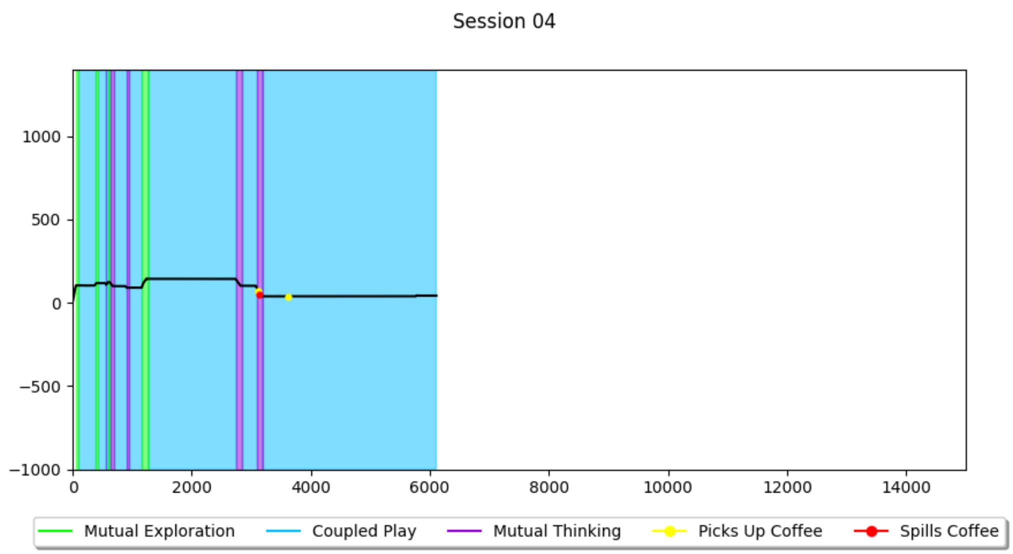

Figure 5.2: Creative sense-making curve from a *Haber Dasher* session. The black line shows the joint creative trajectory curve created by summing the left and right player curves. Shaded regions indicate joint sense-making state. Annotated points represent events during play: coffee pickups nad coffee spills.

ily positive; *mutual thinking* is characterized by a slope is primarily negative; and *coupled play* is characterized by a slope that is close to 0.

Davis' original formal classifications of state based upon slope properties defined creative sense-making states in terms of comparison between the slow-moving average of the slope of the trajectory curve and the fast-moving average of the slope of the trajectory curve [26]. Davis' methods do not specify window sizes for each moving average, nor do they specify how close the fast-moving average and slow-moving average must be for a given period to be considered a period of coupled play. Further, Davis' use of the slow-moving window restricts classification of sense-making states in early stages of play, which prompted the development of a modified version of Davis' classification technique.

Producing sense-making curves that accurately depicted the activities of users required modification of Davis' original guidelines for determining sense-making states. Davis' original method compared the slow-moving average of the joint integral curve to the fast-moving average of the curve. This approach, while allowing for the classification of sense-making states for most parts of the curve, does not allow for state classification at the beginning of a session. This is due to the reliance on slow- and fast-moving averages, which cannot be compared until both are established. In order to allow for analysis of the early sense-making activities in each session (which are not classifiable using Davis' methods), we employed a similar but alternate strategy to identify creative sense-making states. This modified strategy compares the slope of the cumulative sum of players' sense-making values to the standard deviation of the moving average of the integral's slope over the course of the session, which still allows for the classification of slopes as substantially negative, positive, or near-zero just as in Davis et al.'s original formal definitions of each state [18].

The defining characteristics for each state are similar to those outlined by Davis [26] in that they rely on the slope of the cumulative integral curve and describe primarily positive or negative slopes as mutual exploration and mutual thinking, respectively. However, this method allows for state definitions to begin much closer to the beginning of the curve than Davis', since it does not rely on the slow moving average as part of the calculation. The ability to quantify creative sense-making states in the early stages of an interaction allows for the depiction of patterns such as the initial period of mutual exploration in play sessions, as the number of beginning frames that must remain unclassified is only 50 (five seconds of play).

The modified strategy defines states according to the moving average of the slope of the creative trajectory curve. Using state definitions based upon the standard deviation of the slope retains the use of positive and negative slopes as means of delineating states, but allows for the classification of states within 50 frames of session start.

1. ***Mutual exploration*** is defined as a period in which the moving average (using a window of 5 seconds/50 frames) of the slope of the cumulative integral is more than one standard deviation above 0.

2. ***Mutual thinking*** is formally defined as a period in which the moving average of the slope (using the same window) is less than one standard deviation below 0.

3. *Coupled play* is a period in which the moving average of the slope, positive or negative, is within one standard deviation of 0. Davis notes that coupled play may encompass a variety of paired interaction strategies, including states where one player is leading and another is following, both players are clamped, or players exchange periods of clamping [71].

5.2 *Haber Dasher* Analysis

The user sessions for *Haber Dasher* with the two-player hat controller resulted in 16 video recordings. One video was reserved for use in our process for establishing inter-rater reliability. Participants were instructed to sign up with a partner and thus knew the individual with whom they shared the controller. Each dyad played through the entirety of the game, and the session was considered over when players reached the win condition. Dyads' interactions were filmed from two camera angles and analyzed according to the creative sense-making codebook in Appendix A. Gameplay data including the number of pedestrians bumped, number of coffees acquired, and time taken completing in-game tasks were also recorded. Sessions in which participants did not know their partner or experienced technical difficulties such as controller disconnection or errors in video capture were excluded from analysis and were not counted in the 16 session videos.

5.2.1 Codebook Development

Development techniques for the *Haber Dasher* codebook, as well as those for subsequent codebooks, relied heavily on existing creative sense-making literature [18], Expressive Machinery Lab codebooks for creative sense-making analysis of previous projects, and observations made during study sessions by myself and a research assistant. Drawing from Davis' codebooks from his studies on collaborative sketching and pretend play and his generalized descriptions of each sense-making state, we were able to identify guiding terms for each state as it applied to interactions with *Haber Dasher* and the activities we observed during sessions.

Individuals' full physical unclamped states in *Haber Dasher* were primarily based in *exploration*, where players moved the hat controller and observed in-game outcomes to form hypotheses about how the controller worked. Partial physical unclamped states were characterized by *experimentation*; in this state, players proposed and tested hypotheses based upon information previously gleaned from the interaction. In *clamped play*, *Haber Dasher* players focused on *acting* upon their intentions. This action relies upon a player having developed a mental model (either correct or incorrect) of the controller and game, which is then used to guide the player's actions in accordance with their goals. *Partial perceptual unclamped* states were characterized by *thinking*; in this state, players worked to refine their mental models without changing their physical interaction with the controller. *Full perceptual unclamped* states, which occurred rarely in *Haber Dasher* sessions, referred to points of complete *disengagement* in which player actions did not relate to learning about or using the game controller or playing the games. The full codebook for *Haber Dasher* is shown in Appendix A.

These individual guiding terms were augmented with lists of specific behaviors and utterances that frequently occurred in each of the states (for example, hypothesizing language such as "if we do ___, does he ___?"). These exemplar actions and utterances were drawn from frequent player utterances and actions from the *Haber Dasher* sessions. Language was frequently used to contextualize player actions, as many of the movements players performed with the hat could be considered either exploratory, experimental, or clamped based upon players' speech during the session.

5.2.2 Sense-Making Curve Generation

The resultant comma-separated value (CSV) files were trimmed to only include frames of play with the controller and were plotted using PyPlot and MatPlotLib. The NumPy gradient library was used to shade space under the curve in accordance with the joint sense-making state classification based upon the curve's slope as described at the beginning of this section. These plots were augmented by the inclusion of colored points along the curve marking coffee pickups and spills in-game for the purposes of investigating potential relationships between game events and sense-making states. Sample creative sense-making curves from *Haber Dasher* sessions appear in Figure 5.3 and Figure 5.4.

Video recordings of each player were analyzed by one of two video coders using the creative sense-making tool and coding procedure described in Davis (2017) [18]. Video coders analyzed each *Haber Dasher* video for each participant using the creative sense-making video analysis tool [18], with a video speed of 0.75x the original speed. This speed provided longer reaction periods for coders to note state changes while retaining the audio legibility so players' speech could be understood. A sample video was analyzed and divergences in coding were discussed to achieve inter-rater reliability. The video was subsequently re-coded, and the process continued iteratively until a consensus was reached. Once a consensus was reached on the first video, coders anlyzed a second video to confirm that they had reached inter-rater reliability. Inter-rater reliability was calculated using Fleiss' Kappa as described in Davis (2017) [18]. A total of 17,400 codes were compared (8700 codes per player), and the alpha values for the left and right player analyses were averaged to reach an inter-rater reliability score of 0.7496.

Sense-Making Patterns in Haber Dasher

Haber Dasher player dyads generally followed a similar pattern: players first engaged in a period of mutual exploration, which was followed by periods of coupled play interspersed with shorter periods of mutual thinking and occasionally short periods of additional mutual exploration as well; the largest variance in the shape of dyads' sense-making curves was driven by the amount of time spent in the mutual thinking state; some groups had few, smaller periods of mutual thinking, while others exhibited more and/or larger periods of the

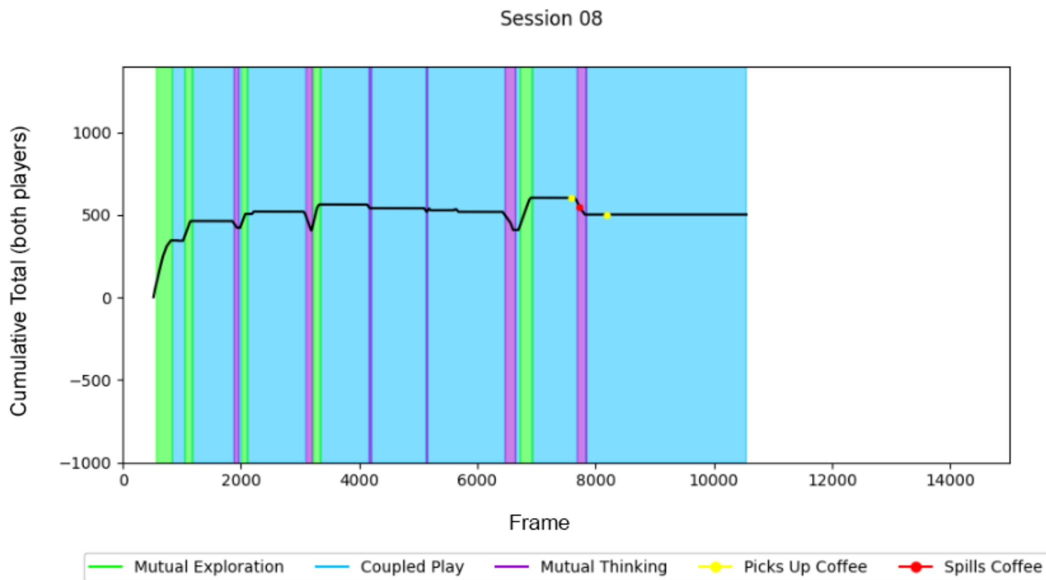

Figure 5.3: Creative sense-making curve from a *Haber Dasher* session with sense-making states shaded. Note the initial period of mutual exploration, followed by periods of coupled play interspersed by shorter periods of mutual thinking.

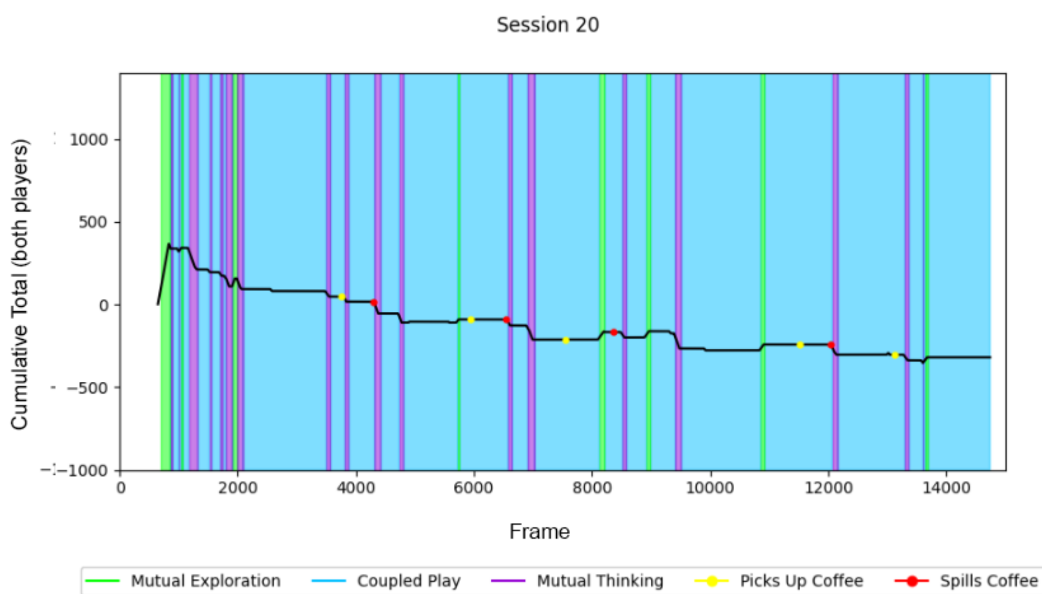

Figure 5.4: Creative sense-making curve from a *Haber Dasher* session with sense-making states shaded and coffee spills marked. Note the periods of mutual thinking immediately following each coffee spill.

same. Furthermore, with only two exceptions, each time any group spilled their avatar's coffee in-game (which occurred 21 times during the 15 sessions analyzed), that action was immediately followed by a period of mutual thinking, in which players asked questions aloud about the game or conversed to renegotiate their use of the controller. This was also observed by the researchers during the play-sessions. This may indicate a relationship between interruptions in play (e.g., a coffee spill) — a moment when a new goal or event occurs in play that asks players to immediately shift their course of action — and players re-engaging in discovering rules of the game, control system, or play-world.

5.3 *Sound Happening* Analysis

Sound Happening was installed in a public green space during Georgia Tech's Week of Welcome in August 2022. Players were recruited from the attendees of a first-year welcome week event and were instructed to interact with the installation for as long as they felt like and leave when they desired. The large size and outdoor nature of the event allowed for the recruitment of a large number of participants due to foot traffic in the area. The installation was set up in a 10x10 foot space under a tent on a green space adjacent to a sidewalk. Sessions in which one or both users had existing knowledge of how the installation worked after conversing with a facilitator were excluded from analysis. Sessions in which one or both players had previously interacted with the installation were included in the analysis. We analyzed video data of 41 dyads interacting with the installation. Player interactions were recorded with one camera, which was aimed through a side of the rectangular play-space that was bounded by brightly colored cord.

5.3.1 Codebook Development

The codebook development process for the *Sound Happening* installation drew from existing creative sense-making literature and researcher observations, as well as the prior development of the codebook for *Haber Dasher* and an existing codebook from the installation and analysis of an earlier version of *Sound Happening* at a children's museum. The guiding terms for each state were altered slightly from the *Haber Dasher* codebook to reflect actions taken in a space where the physical interface included multiple separate parts that could be thrown, lost, or exchanged. Further, the open-ended nature of the *Sound Happening* installation (as opposed to the goal-centered interaction provided by *Haber Dasher*) resulted in the changing of the guiding term for partial physical unclamping to *testing* to more accurately reflect players' actions with the installation. The term *gathering* was added to the guiding terms for full physical unclamping to include actions where interactors work to physically collect resources (beach balls that were on the ground or outside the play-space). Unlike in *Haber Dasher*, there were several occurrences of full perceptual unclamping in the *Sound Happening* sessions, which included actions such as interactors throwing the balls at one another with no regard for the sound, putting balls down or preparing to leave the space, or otherwise interacting in the space without regard for the sonic output.

Language was not used as a primary component of the *Sound Happening* analysis due to the nature of the recordings collected. The artifact's sound-based nature, amplification system, and installation outdoors meant that audio beyond the sounds produced by the system itself, including dialogue, were not often audible or distinguishable in the recordings. Thus, the codebook for *Sound Happening* exclusively uses physically-based behavioral markers to describe sense-making states.

Three coders analyzed the *Sound Happening* video recordings. We again utilized an iterative coding process to establish inter-rater reliability. All three coders analyzed a sample video, after which points of difference in coding were identified and discussed, and the video was re-coded. Inter-rater reliability was calculated using the averages of Fleiss' Kappa calculated for codes for the left and right players. In total, 1134 codes were compared (567 for each player), and an IRR score of 0.653 was achieved.

5.3.2 Sense-Making Curve Generation

The sense-making curves for *Sound Happening* dyads were generated and shaded using the same process as those produced for *Haber Dasher*, using the same window sizes (50 frames and 500 frames) for the moving average of the slope. No additional events were plotted on the sense-making curves for *Sound Happening*. The sense-making chart for session 7 was not able to be shaded automatically due to a consistent downward slope in the creative trajectory curve for nearly the full duration of the session, which primarily included the two participants throwing beach balls at one another. This curve has been classified as a state of mutual thinking due to the downward slope of the creative trajectory, although it should be noted that the "mutual thinking" in this case (and perhaps others) refers to a complete perceptual disconnection and/or disengagement from the interaction.

In general, sense-making curves for *Sound Happening* include substantial periods of mutual exploration during the beginning of play. In some sessions, this continues, interspersed with coupled play, for the duration of the session. In others, players transition into periods of time that are primarily composed of mutual thinking states. This may be due to a loss of interest in the system before players decide to leave the play-space. Sense-making curves from two *Sound Happening* sessions are shown in Figure 5.5 and Figure 5.6.

5.4 *Trip: A Cosmic Adventure for Two* Analysis

We collected recordings of 15 user sessions for use analyzing *Trip* (Sessions in which unexpected technical difficulties occurred were excluded from analysis and are not counted among the 15 videos). At the beginning of each session, players were asked to choose the "driver" or "navigator" role, but were not given any further information. Players entered the play-space from opposite sides and did not see one another's controllers before play began. Sessions were recorded using a single camera aimed at players' screens, which captured both players' platforms, controllers, and interfaces.

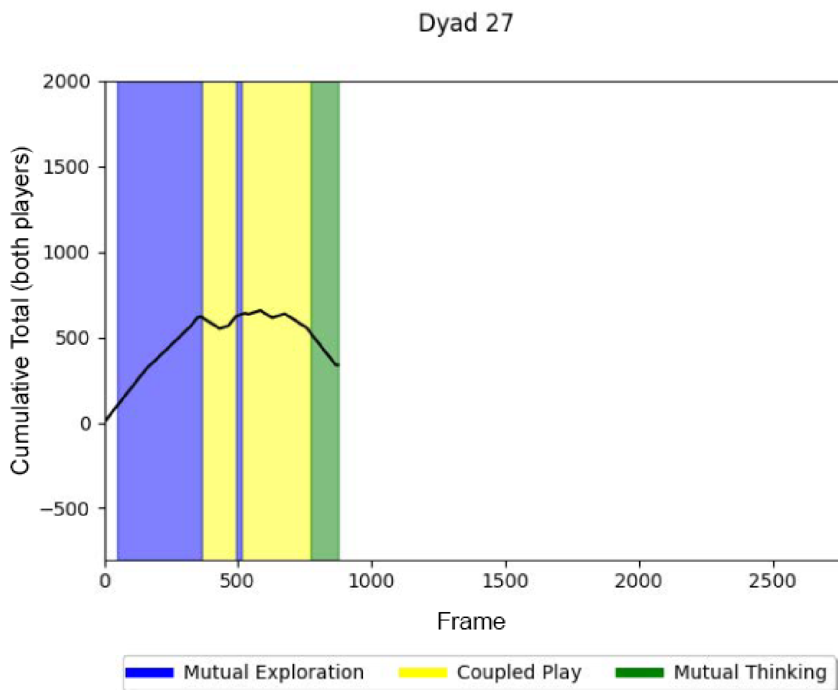

Figure 5.5: Creative sense-making curve from a *Sound Happening* session in which players engaged in mutual exploration, coupled play, and finally mutual thinking.

At the beginning of the play session, players were invited to step onto the game platforms, and the driver was instructed to wait to step onto the balance ball until the game instructed them to do so (after the calibration routine had completed). After calibration, players were given an audio briefing in game providing thematic content relating to the premise of the game. The briefing introduced the players' roles as astronauts, noted that hallucinogens were detected in the atmosphere of the planet, and instructed players to take off and return to safety. Players played through the game until they reached a "game over" state.

If players reached game over during the first level, they were offered the opportunity to play again (but were not offered any additional information). Portions of the session where players waited for a facilitator to restart the game were excluded from analysis. In cases where sessions lasted longer than thirty minutes, players were permitted to leave after the thirty-minute mark to comply with the submitted IRB protocol and only the first

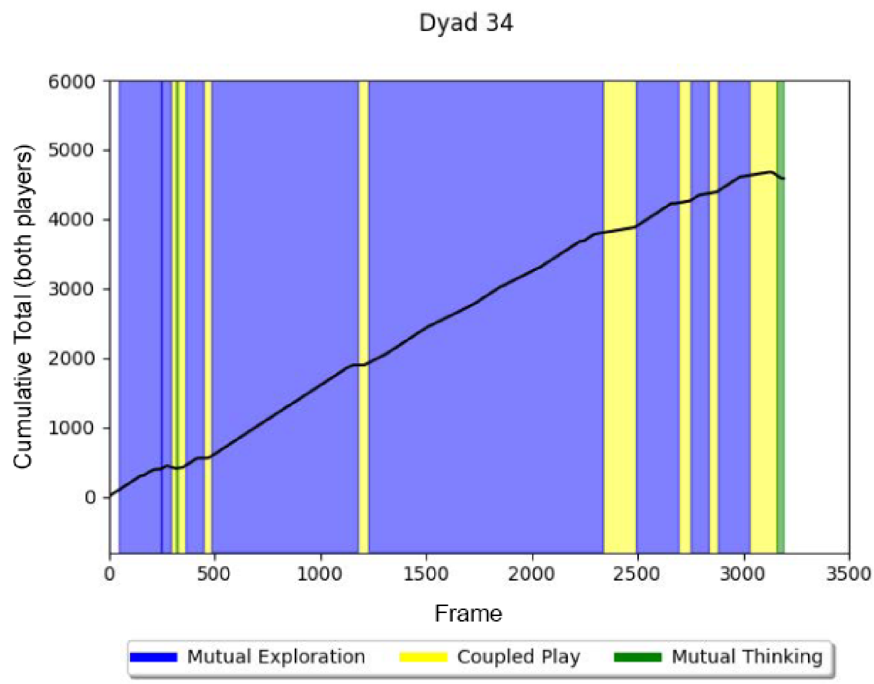

Figure 5.6: Creative sense-making curve from a *Sound Happening* session in which players engaged in mutual exploration and coupled play during most of the session.

thirty minutes of gameplay were analyzed. The only occurrence of this was a group that experienced difficulty discerning the goal of the game and played for more than thirty minutes without completing a level.

5.4.1 Codebook Development

Due to the goal-based nature of *Trip*, the codebook for user sessions drew heavily on that developed for *Haber Dasher*. Two guiding terms, *observing* and *refining*, were added to those for the *partial perceptual unclamp* state to reflect players' actions during play, in which much of the thinking process was accompanied by observing the outcome of their partners' actions and discussing the game and controllers with their partner.

The primary difference, however, between the codebook for *Trip* and those used for *Haber Dasher* and *Sound Happening* is the movement of testing a partner's hypothesis from the *partial perceptual unclamp* category to the *partial physical unclamp* category.

This change was made to account for the fact that *Trip* does not include shared control artifacts such as the beach balls in *Sound Happening* or the *Haber Dasher* hat, and instead asks each player to control the portion of the output visible to their partner. In cases where control artifacts were shared, players testing a partner's hypothesis typically followed partners' instructions or physically supported their desired physical experimentation (for example, tilting the hat along with their partner when instructed to do so). However, in *Trip*, players testing their partners' hypotheses about controller functions had sole responsibility for enacting that test action physically. Thus, while the hypotheses may have been generated by the partner ("try spinning around"), the actual physical experimentation was carried out by the player and not their partner.

Inter-rater reliability was calculated using the averages of Fleiss' Kappa calculated for codes for the left and right players. In total, 13,803 codes were compared (6901 for one player and 6902 for the other), and an IRR score of 0.649 was achieved.

5.4.2 Sense-Making Curve Generation

Sense-making curves for *Trip* sessions were generated and shaded using the same process and state definitions as the curves for the other artifacts. Sessions in which players failed to complete the first level and restarted the game required editing during this process. Though this short period while a facilitator restarted the program often included some player dialogue, such utterances were minimal and occurred outside the of play. For this reason, these time periods were excluded from creative sense-making analysis. These frames were removed from the sense-making curves.

Sense-making curves for *Trip* were augmented with the plotting of three additional key events. These include the completion of the first level (shown as a green dot), the first appearance of a model of a control object on the Driver's screen (shown as a red dot), and first correct identification and interaction of a control object (shown as a blue dot). Sense-making curves from *Trip* dyads exhibit a wide variety of properties, and can be described as more variable than the curves describing dyadic interactions with the other artifacts here.

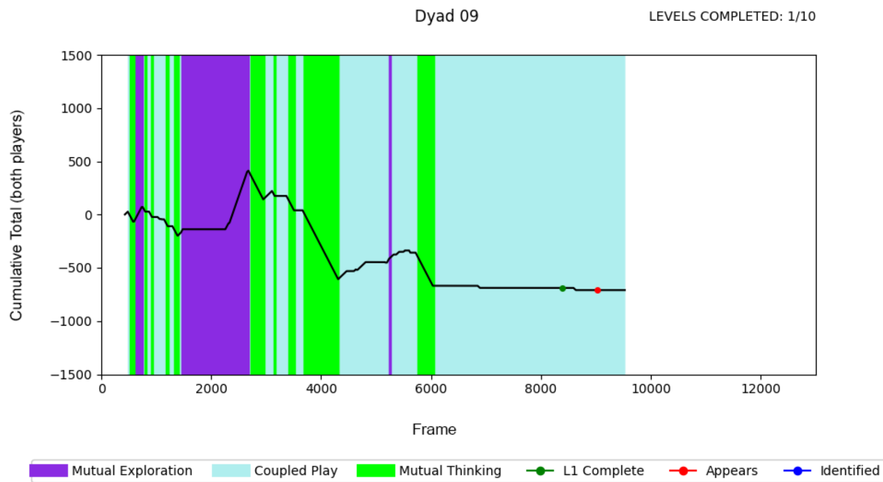

Figure 5.7: Creative sense-making curve from a *Trip* session in which players engaged in various sense-making states throughout the session.

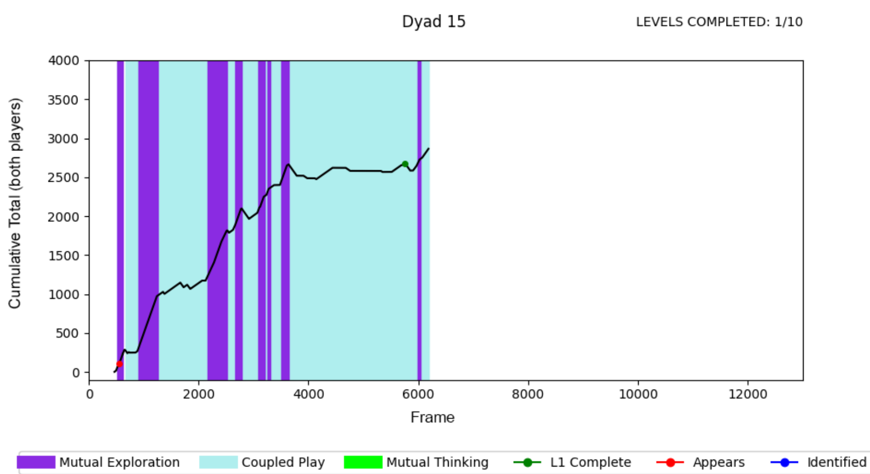

Figure 5.8: Creative sense-making curve from a *Trip* session in which players engaged in alternating periods of coupled play and mutual exploration.

5.5 *Haber Dasher* Controller Condition Analysis

A second set of *Haber Dasher* user sessions was conducted using the modified gamepad-control version of *Haber Dasher* to investigate whether the sense-making patterns of dyads engaged in collaborative play with traditional controllers exhibited similar properties to those using alternative controllers. We collected video data of 15 user sessions with the gamepad-control version of *Haber Dasher*. The gamepad condition sessions were conducted in a small conference room in the same building as the lab setting used for the other indoor studies. Players were instructed to sit on opposite sides of a conference table and used wired Xbox gamepad controllers. These sessions were recorded with one camera, which was aimed at players' hands and gamepad controllers. The session procedure was nearly identical to that used for the *Haber Dasher* hat condition, with the exception of the instructional screen and language used before gaemplay began. The gamepad version includes a modified briefing screen that shows an animated simplified gamepad graphic in place of the animated hat object. Verbal instructions given to players were modified to include directions to use the gamepad thumbsticks.

5.5.1 Codebook Development

The codebook for the *Haber Dasher* gamepad condition was highly similar to the existing *Haber Dasher* hat condition codebook to allow for comparisons between the two conditions. Modifications made included clarifying language in the original codebook and changed references of physical manipulation of the hat controller to instead refer to physical manipulation of the joysticks on the player's gamepad controller.

A 16th sample video was also recorded for use in the iterative coding to establish inter-rater reliability. Once coders had reached a consensus on the sample video, a second video was coded to establish an inter-rater reliability score. 14,158 codes (7079 per player) were compared, and the coders for the *Haber Dasher* gamepad videos achieved a Fleiss' Kappa of 0.679.

5.5.2 Sense-Making Curve Generation

Sense-making curves for the *Haber Dasher* control condition were generated using identical methods to those used to create the sense-making curves for the hat controller con-

Table 5.1: Inter-rater reliability data for all four sense-making analysis

Artifact	**Codes Compared**	**Fleiss' Kappa**
Haber Dasher Hat	17,400	0.750
Sound Happening	1,134	0.653
Trip	13,803	0.649
Haber Dasher Gamepad	14,158	0.679

dition. This included the plotting of coffee pickup and spill events during play along the sense-making curve.

5.6 Analysis of Sense-Making Curves and Trends

In addition to the production of shaded and annotated creative trajectory curves for each session across all four artifacts, I present here additional means of summarizing and visualizing the sense-making data from these studies, which can illustrate generalizable properties of sense-making processes on a per-artifact basis. A primary challenge of condensing sense-making curve data into a useful representation of all sessions with an artifact is the challenge of working with sessions of highly variable length; for example, *Haber Dasher* creative sense-making data ranged from 4,249 frames in length to 14,089 frames in length. This creates difficulty in generating, viewing, and manipulating generalizable data for a given artifact. The creation of summary curve information based on progress through a session rather than number of frames can help alleviate this issue and produce visual information that can yield insights into the sense-making processes of all dyads. Below, two such summary charts are presented: charts outlining the occurrence of sense-making states as related to session progress, and charts outlining the most prevalent state for each session as related to session progress.

These visualizations, coupled with the creative trajectory curves for each artifact, fully or partially confirm several hypotheses concerning the relationships between physical affordances and sense-making properties in the activities of player dyads. Firstly, and most importantly, these visualizations confirm that distinct sense-making patterns can be detected in play with different artifacts. A clear example of this is the obvious difference between sense-making states in *Sound Happening* and those seen in the goal-based games; the aggregate *Sound Happening* shows a much greater amount of mutual exploration than the aggregated data for *Haber Dasher* and *Trip*, suggesting a potential relationship between goals, exploration, and coupled play. Further, the creative sense-making data (both trajectory curves and aggregate data) partially support other hypotheses, marking potential areas for future investigation. For example, the annotated creative trajectory curves from the *Haber Dasher* hat condition indicate the strong potential for a relationship between interruptions and mutual thinking. However, the annotated curves from *Trip* do not show mutual thinking after any particular event; whether this is caused by physical affordance, the nature of the game or information given, or other factors remains an open space for additional experimentation. Similarly, some properties of the aggregate data can be mapped to specific properties within the alternative controllers taxonomy proposed in Chapter 3, but others do not map as clearly. Development and creative sense-making analysis of additional artifacts within this design space may help to support greater clarity as to potential relationships between taxonomy positions and sense-making patterns.

5.6.1 Occurrence of Sense-Making States By Session Progress

Plotting the occurrence of creative sense-making states in relation to the 1/1000th or 1/100th of a session in which they occurred allows for the discernment of when different creative sense-making states occur during sessions with a particular artifact. Slices of 1/1000th were selected for *Haber Dasher* and *Trip* to provide a large number of "slices" while retaining multiple frames in each slice even for shorter sessions. Since the sessions for *Sound Happening* were substantially shorter than those for other artifacts and frequently less than

1000 frames, a slice size of 1/100th was used instead to retain detail while accounting for sessions less than 1000 frames in length.

This method of slicing session data allows for the production of charts like those shown in Figures 5.9 - 5.12, which outline the frequency at which each creative sense-making state occurs during parts of a session. These charts plot a bar for each of 1000 slices of the total frames for all sessions with an artifact. The height of the bar is determined by the number of sessions in which the given sense-making state was present at least once during the given 1/1000th of the play session.

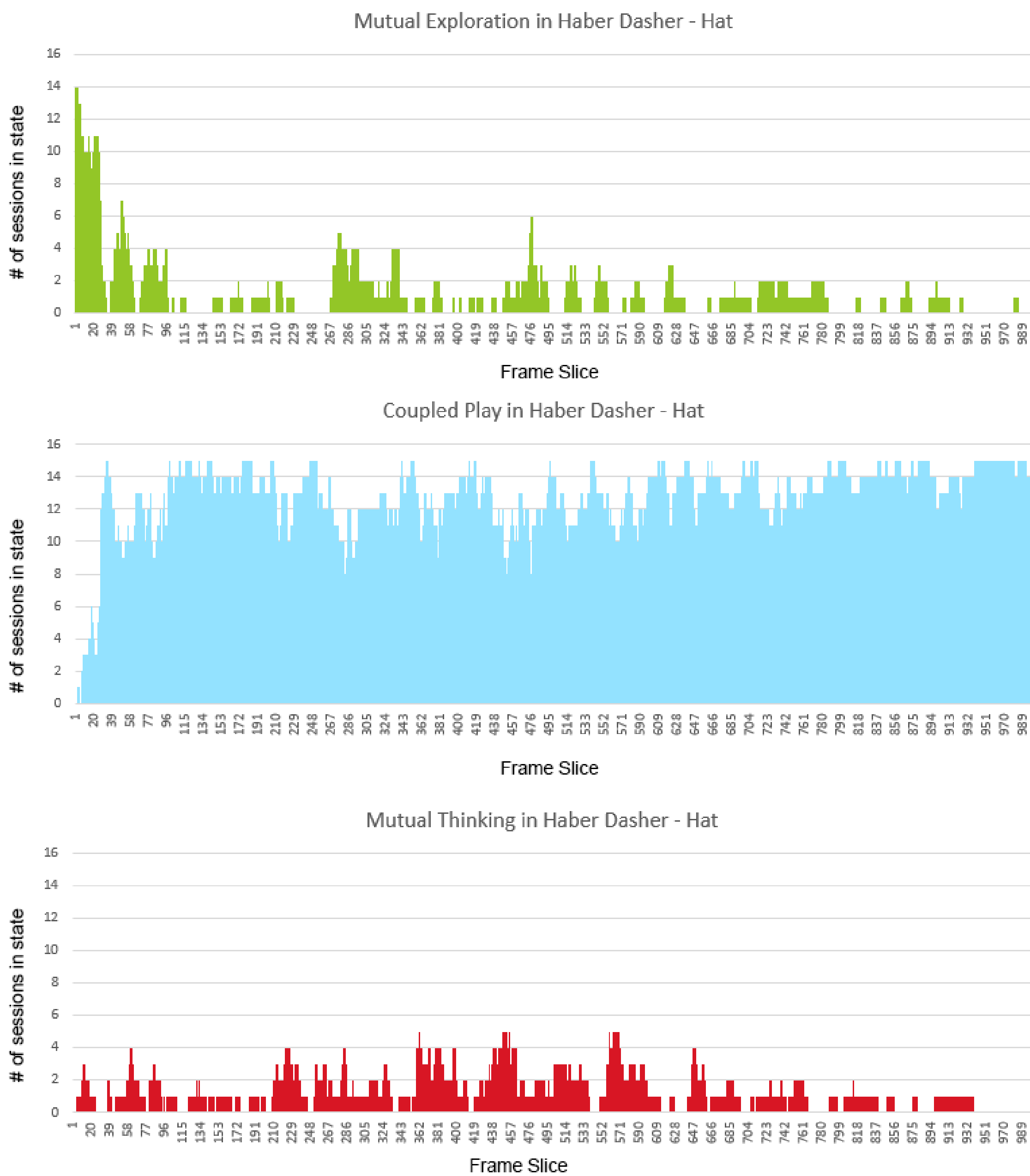

Figure 5.9: Sense-making state occurrence per 1/1000th of session for *Haber Dasher*.

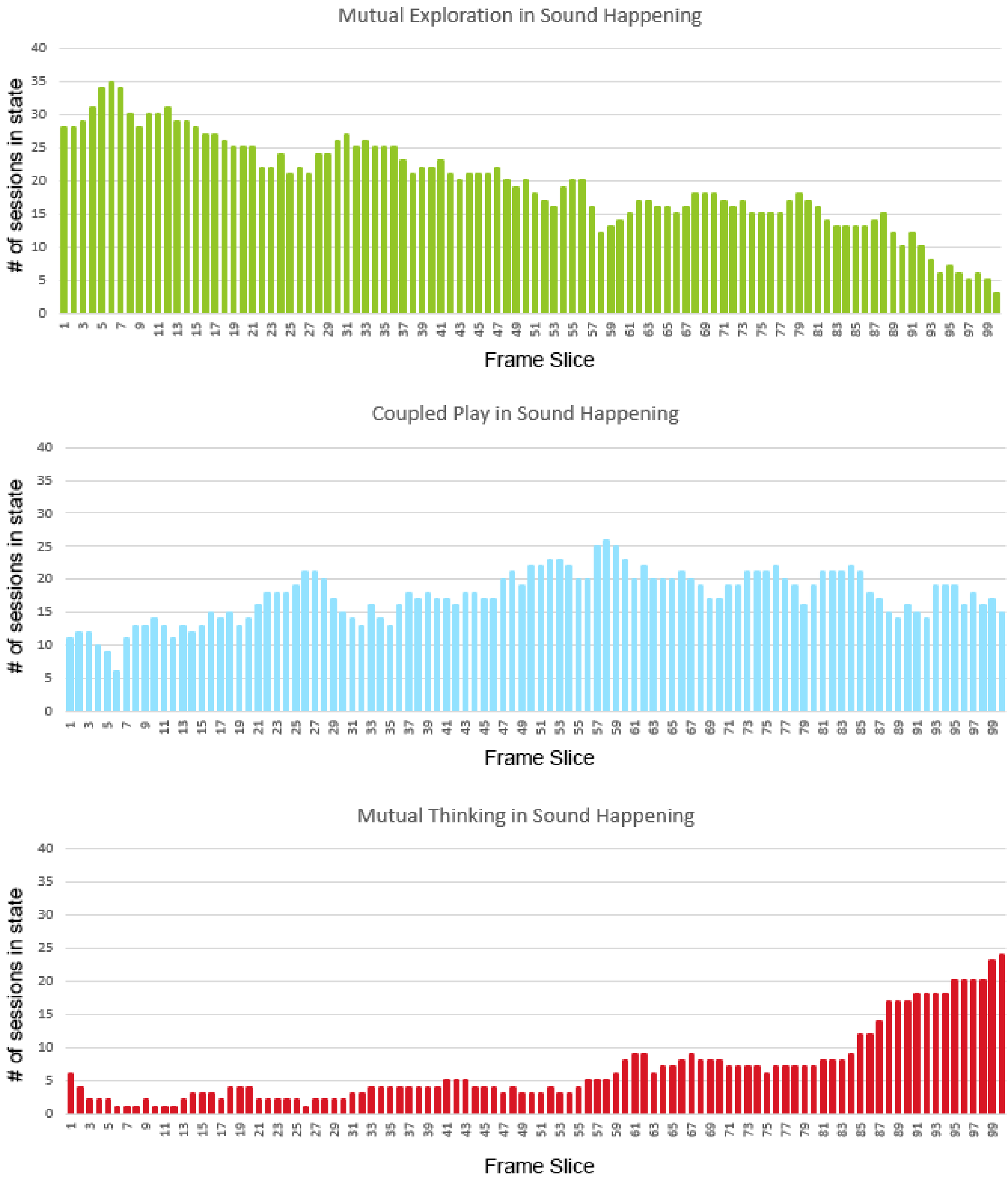

Figure 5.10: Sense-making state occurrence per 1/100th of session for *Sound Happening*.

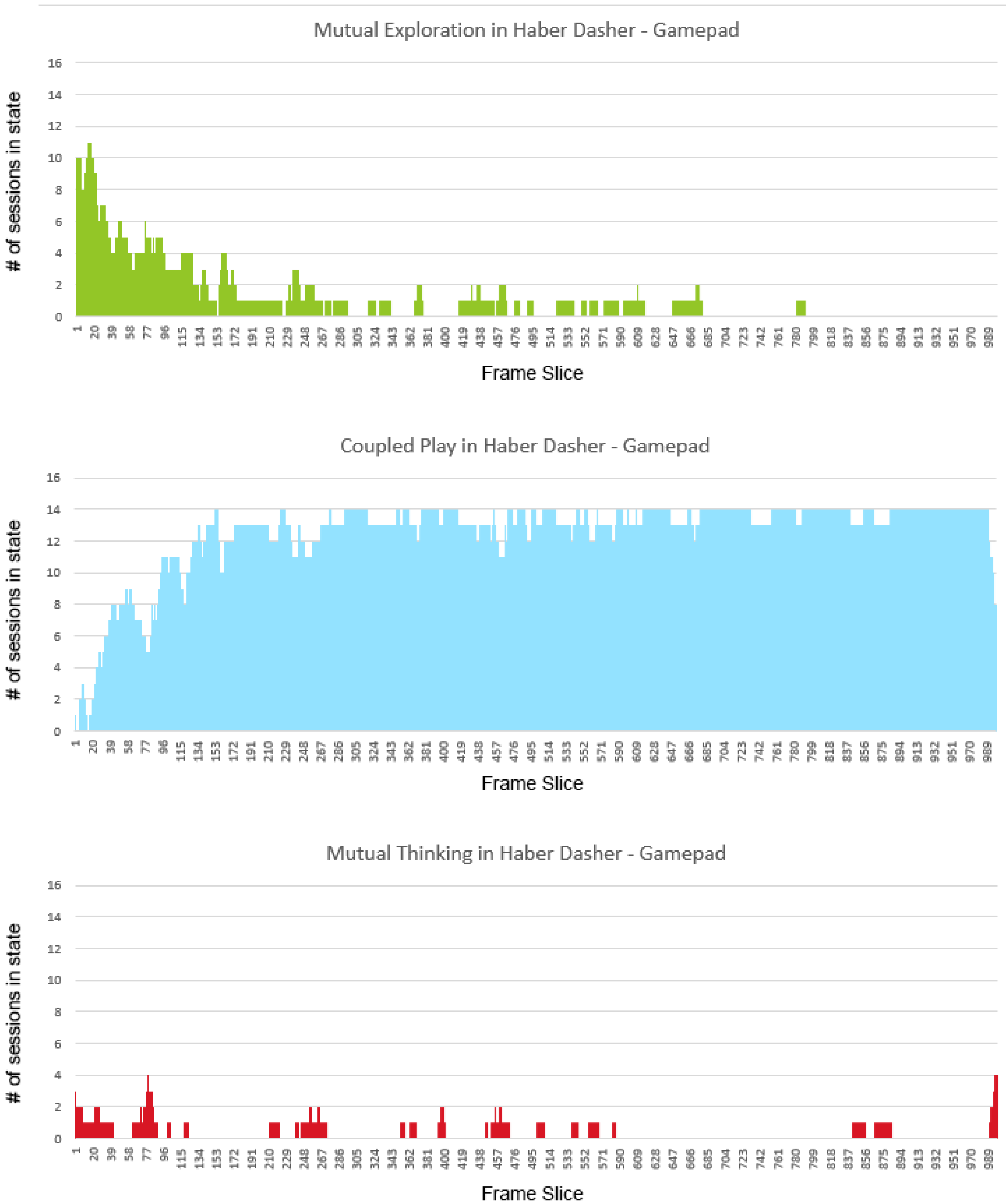

Figure 5.11: Sense-making state occurrence per 1/1000th of session for the *Haber Dasher* gamepad condition.

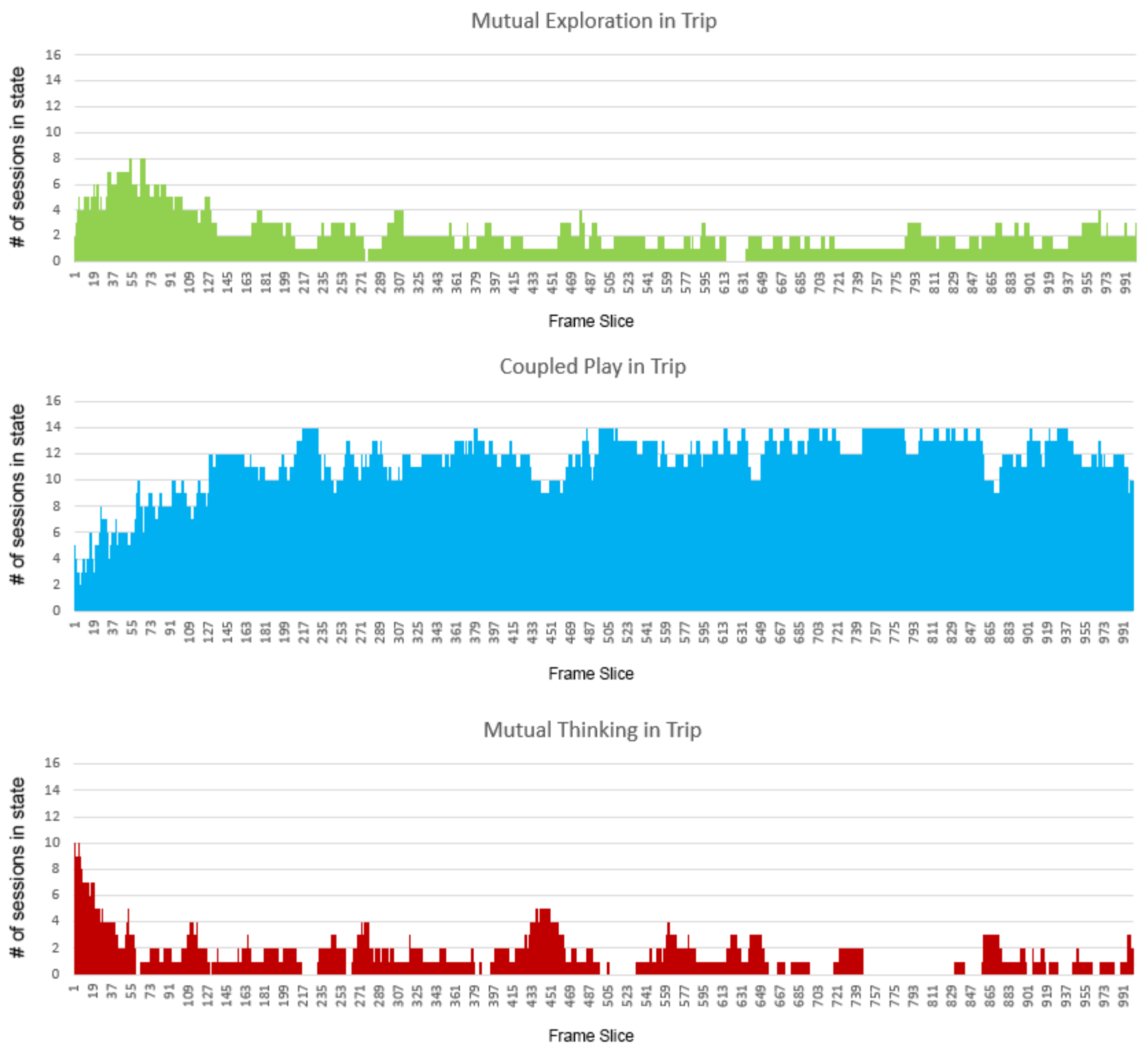

Figure 5.12: Sense-making state occurrence per 1/1000th of session for *Trip*.

Occurrence of States for Alternative Control Artifacts

The graph showing occurrence of the *mutual exploration* state during *Haber Dasher* sessions confirms the initial spike in and quick transition out of *mutual exploration* at the beginning of *Haber Dasher* sessions suggested by the body of sense-making curves for the artifact, indicating that most *Haber Dasher* dyads engaged in a relatively brief period of *mutual exploration* then moved to a state of either mutual thinking or coupled play after a short time.

Also of interest is the contrast in coupled play occurrence in *Haber Dasher* and *Sound Happening* sessions, shown in Figure 5.13. Coupled play occurs very frequently throughout most of the session slices for *Haber Dasher*. In *Sound Happening*, coupled play occurs far less frequently overall, and reaches a peak near the halfway mark of sessions before decreasing slightly until the end of sessions. This may be due to the lack of a gameplay goal in *Sound Happening* or in the greater complexity of the relationships between inputs and outputs relative to the *Haber Dasher* control scheme.

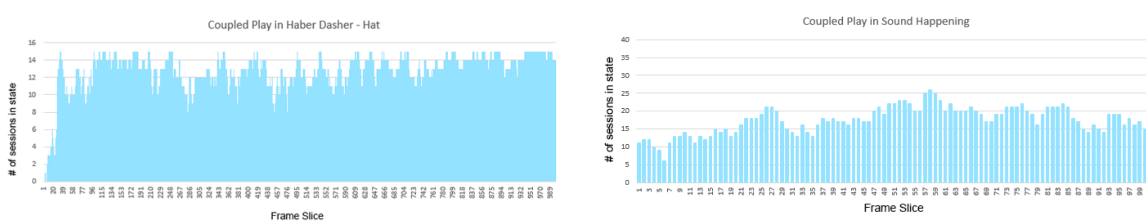

Figure 5.13: Coupled play occurrence in *Haber Dasher* and *Sound Happening*.

Occurrence of States for Haber Dasher Conditions

Of note in the state occurrence charts for the two conditions for *Haber Dasher* is the shape of the occurrence chart for the mutual exploration states at the beginning of play sessions, shown in Figure 5.14. Both controller conditions' occurrence charts indicate that a majority of dyads were in a state of mutual exploration during the first stage of play. However, there is a distinct difference in the shape of the occurrence charts for each version for mutual exploration after the initial spike. Dyads in the hat controller condition rapidly transitioned out of the initial state of mutual exploration, while the length of this period among gamepad dyads was much more variable.

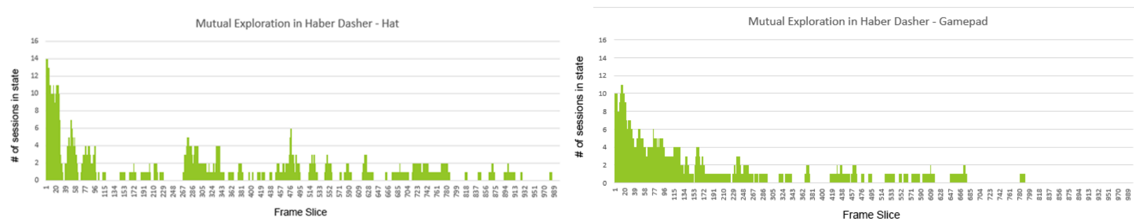

Figure 5.14: Mutual exploration occurrence in *Haber Dasher* conditions.

The prevalence summary chart for players in the each condition show an additional notable feature. Periods of mutual thinking were more frequent during play in the hat controller condition than in the gamepad controller condition, indicating that players spent more time asking questions and making observations when interacting with the alternative-control version of the game. The occurrence charts for the *Haber Dasher* hat controller sessions additional show much more variability in the number of sessions in coupled play at any given point; in contrast, there are several points in the gamepad condition occurrence chart in which almost all dyads were in coupled play. This indicates a greater degree of play interruption for thinking or exploration with the alternative controller, and may suggest that the novel alternative controller supported greater exploratory and observational interaction than the gamepad controller.

5.6.2 Most Prevalent Sense-Making State By Session Progress

A similar plotting method allows for the display of state prevalence within a session. The below charts display the most prevalent state in all sessions for an artifact, again using a 1/1000th slice. The most prevalent state in a session slice is defined simply as the state which appears most frequently during the frames included in the slice. For session slices which did not have a single state that was more prevalent than the two others, a value of NONE was recorded. The below charts display this data two ways. The first chart for each artifact shows data for all sessions, with NONE values included. The second chart for each shows the same data, but with NONE values excluded and bar height representing a percentage of the remaining sessions.

Figure 5.15: Most prevalent sense-making state per 1/1000th of session for *Haber Dasher*.

Most Prevalent State for Alternative Control Artifacts

The charts showing the most prevalent state by session progress show an initial period of mutually unclamped behavior (mutual exploration and mutual thinking) near the beginning of sessions for all three. They additionally illustrate a clear distinction between patterns of exploration and coupled play in the goal-based game artifacts and the open-ended interaction of *Sound Happening*. In many sessions with the game artifacts, the majority of dyads were in a state of coupled play for a large number of the session slices.

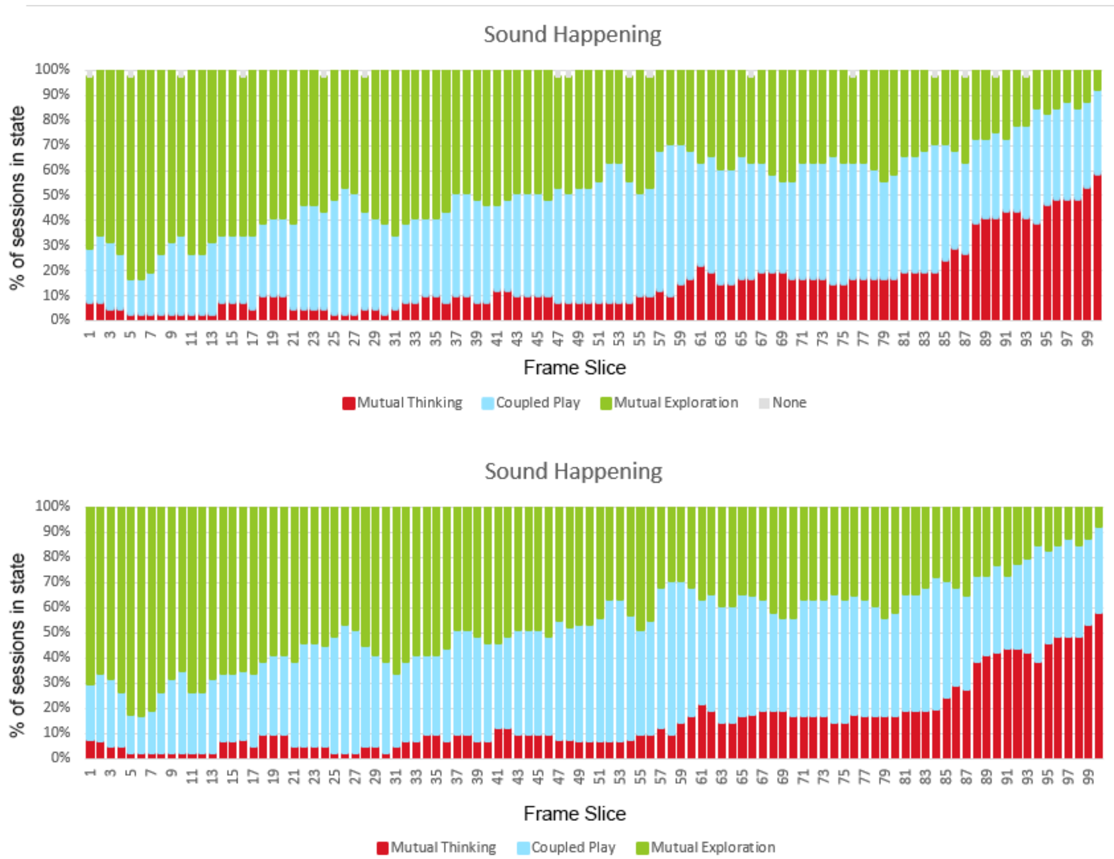

Figure 5.16: Most prevalent sense-making state per 1/100th of session for *Sound Happening*.

Most Prevalent State for Haber Dasher Conditions

The charts showing the most prevalent state by session progress for the *Haber Dasher* conditions show some differences between sense-making processes of players engaged with the hat controller versus those using the gamepad controllers. Notably, the initial period of mutual exploration is more variable in length in the gamepad condition, whereas players in the hat control condition transfer out of mutual exploration rapidly. This may indicate that the simplicity of the hat controller led to players learning the control scheme faster. However, there is less prevalence of mutual exploration after the initial period in the gamepad condition than in the hat control condition, indicating that the hat may have prompted additional moments of mutual exploration after the initial period. This may be caused by players' lack of an existing mental model of the hat controller; players may have been

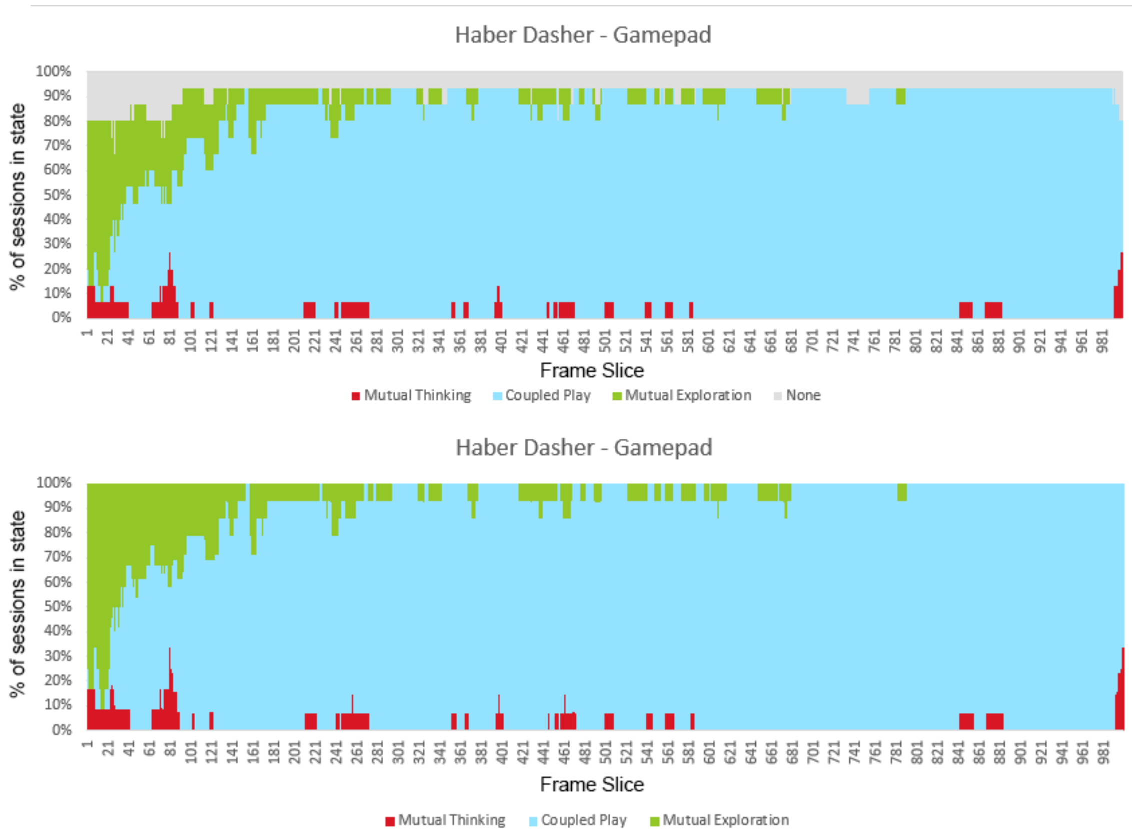

Figure 5.17: Most prevalent sense-making state per 1/1000th of session for the *Haber Dasher* gamepad condition.

able to figure out the joystick control using previous knowledge, and apply that even when the game state changed, while game state changes may have required additional resource gathering with an unknown controller.

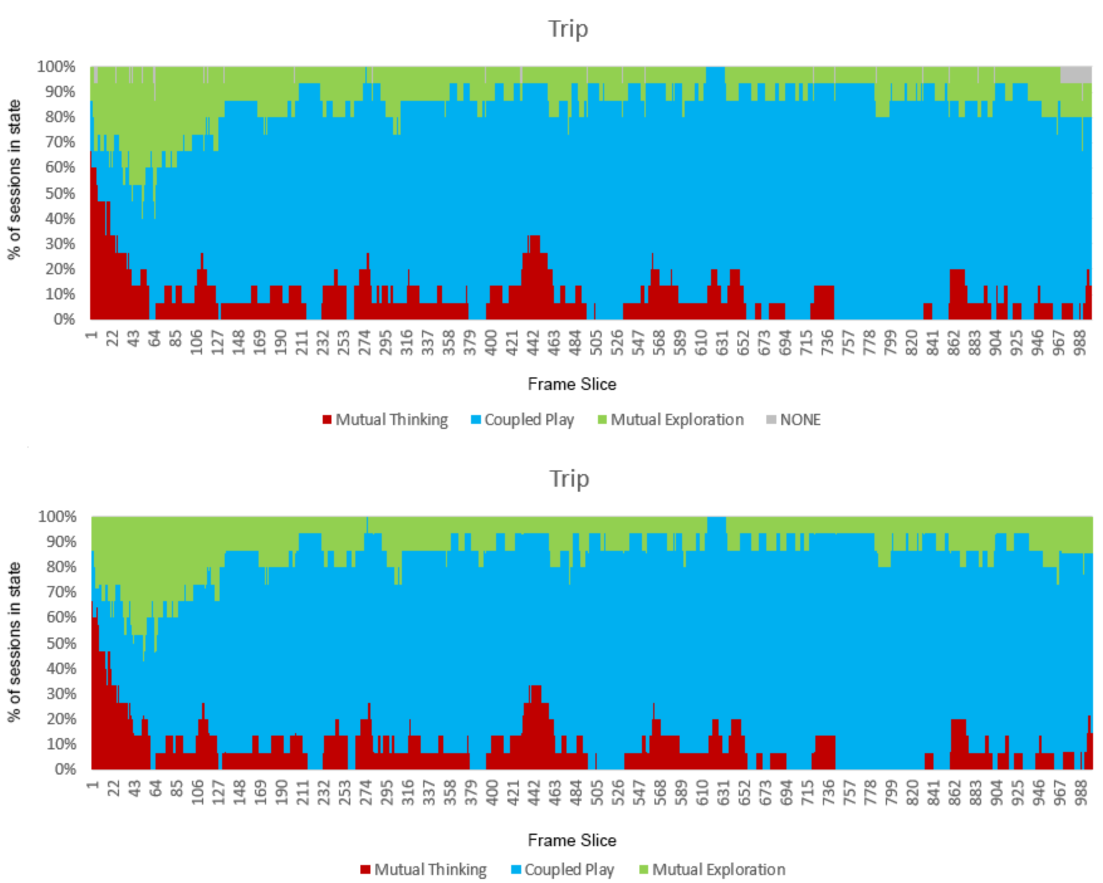

Figure 5.18: Most prevalent sense-making state per 1/1000th of session for the *Trip*.

CHAPTER 6
DESIGN GUIDELINES

This chapter details the outcome of the design, implementation, and creative sense-making analysis of the three artifacts detailed in Chapters 4 and 5. Descriptions of shared properties in the design of the three boundary artifacts are enumerated. These shared properties were used to develop design guidelines drawing on familial relationships among the included artifacts as well as the creative sense-making analysis used to describe collaborative play with each. These design guidelines are outlined at the end of this chapter.

6.1 Shared Qualities

Enumerating the qualities shared among all three artifacts allows for the description of each controller in light of the shared qualities, highlighting both design aspects that apply to all three artifacts as well as the differences in ways those qualities are expressed in each. This also allows for the description of two relevant dimensions of sense-making analysis for each controller: length and variation in length of an initial period of mutual exploration, and prevalence of coupled play, which are highlighted for each artifact. This section enumerates the qualities and aspects of sense-making data that served as the basis for the design guidelines presented in this chapter.

Opportunities for deflecting embarrassment. The three artifacts presented here share the inclusion of one or more mechanisms for allowing participants to engage in ways that reduce the potential for embarrassment — and therefore the social risk — of play. In each, play among adults is encouraged by the creation of opportunities for distancing oneself from the role-claims of play or otherwise keying play in a way that does not threaten the claims of adulthood of players [42]. Allowing avenues by which players may deflect the embarrassment potential of play and playful activity ensures that players are able to interact within a socially safe play-space.

A useful and easily integrated means of offering embarrassment deflection opportunities is the use of humor in one or more components of the activity. The games included in this thesis (*Trip* and *Haber Dasher*) demand actions that are highly disparate from everyday life from their players, offer the deflection of sincerity or earnesty and ironic keying through the use of humor, allowing for exaggerated performance and nonserious interaction.

An additional means of offering players means of deflecting the potential for embarrassment is the opportunity for “role distancing”, allowing the player to detach from the role they are performing [42]. *Sound Happening* allows for interaction without a great deal of buy-in, and offers a readily accessible means by which to do so due to the simplicity of interaction requirements. Players may distance themselves from the role of “player” by rejecting playful action and merely standing in the space or by rejecting the implied aims of the installation by throwing the balls at one another and ignoring the musical output entirely.

Physically defined play-space boundaries. While play-spaces do not require definition in the physical world (boundaries may also be metaphorical or temporal), the controllers developed for this dissertation define play-spaces using physical means to delineate the bounds between “in the game” and “outside of the game.” This design quality makes the physical play area visible from the perspectives of both players and spectators and can be viewed as a means of addressing the *social spaces* theme by giving physical form to the boundaries of the play-activity.

Shared resources and responsibilities. The artifacts presented here share mechanisms for promoting the sharing of both *resources* and *responsibilities*. In each experience, players share responsibility for a single output - ship health, avatar movement, or audio output. In non-goal based environments, this can be viewed as a result of both the controller and game mechanics, where the primary actions necessary for completing the goal(s) of the game require the interaction of more than one player. Beyond sharing output responsibilities, players additionally share responsibility for control inputs, jointly managing multiple or oversized control objects during play.

The resources available to each player are limited to a subset of the total controls available. This limitation was achieved by a number of means, including the use of controllers for which it is physically impossible or highly difficult to interact with all inputs at once. By designing for collaboration in both the input and output dimensions of interaction, players were brought into coupled action, constantly acting and reacting to one another's actions as they negotiated shared use of the control object(s) towards agreed-upon ends.

Exploratory behavior prompted by controllers and digital mechanics. Both controllers and game and interaction mechanics for *Haber Dasher*, *Trip*, and *Sound Happening* prompted exploratory behavior (states of mutual thinking or mutual exploration) among player dyads. Complex controls prompted players to experiment physically with their controllers to determine how to achieve their roles. Design choices that furthered this effect (which can be seen in the occurrence of mutual thinking and mutual exploration) include the choice to limit information given to players before beginning play, as well as the inclusion of multiple control inputs (particularly in the case of *Trip* and *Sound Happening*).

Interruption of coupled play-states with in-game events serves a similar purpose, prompting states of mutual thinking as players engage with the game's rules to negotiate their next steps during play. This is visible in the sense-making data from *Haber Dasher*, in which a coffee spill was nearly always followed by a state of mutual thinking as players asked questions of one another about what they were required to do next.

6.1.1 Relevant Aspects of Sense-Making Analysis

In addition to the theme-based descriptions provided for each artifact, I also provide descriptions relating to key elements of the sense-making patterns seen from user sessions. The usage of creative sense-making as a lens for analysis of embodied play provides data that can be used to supplement design-based descriptions by providing insight into player experiences with the included artifacts. The data available from this analysis offers a view of play that adds an additional dimension to support the claims and themes arising from the juxtaposition of the artifacts in the portfolio.

Duration of initial period of mutual exploration. The length of the initial period of mutual exploration with an artifact, as well as the amount of time taken by players to transition out of that initial state, is a useful means of understanding how long it takes players to learn how to use a controller and how quickly that learning is translated into an actionable mental model of how the controller works. Examining this pattern can be used to highlight the means by which controllers and games may support different types of play-experiences, and which properties may emphasize or disincentivize exploration. This is clearly visible in the charts outlining the most prevalent states over the course of a session (as shown in Figure 6.1). The periods of mutual exploration among *Haber Dasher* and *Trip* players tended to be very short, with a substantial number of sessions transitioning to coupled play or mutual thinking fairly rapidly. In contrast, the summary data for *Sound Happening* shows much more variance in the length of initial mutual exploration. The state is still most prevalent at the beginning of sessions, but there remains a substantial number of sessions within the mutual exploration state much farther into the chart than is seen in that of the game artifacts.

The length and variation in length of initial states of mutual exploration offers a viewpoint of players' actions when "figuring out" a controller and thus insights into players' learning process when interacting with the artifact (as shown in Figure 6.2). The length can also indicate how much exploratory action is emphasized in an artifact: mutual exploration occurring throughout sessions indicates ongoing experimentation by players. Designers can view this as a tool to guide design modification based upon the desired amount of time spent in experimental activity or ease of learning a control scheme, or to uncover new questions about factors that may relate to the speed at which dyads build a mental model of a controller.

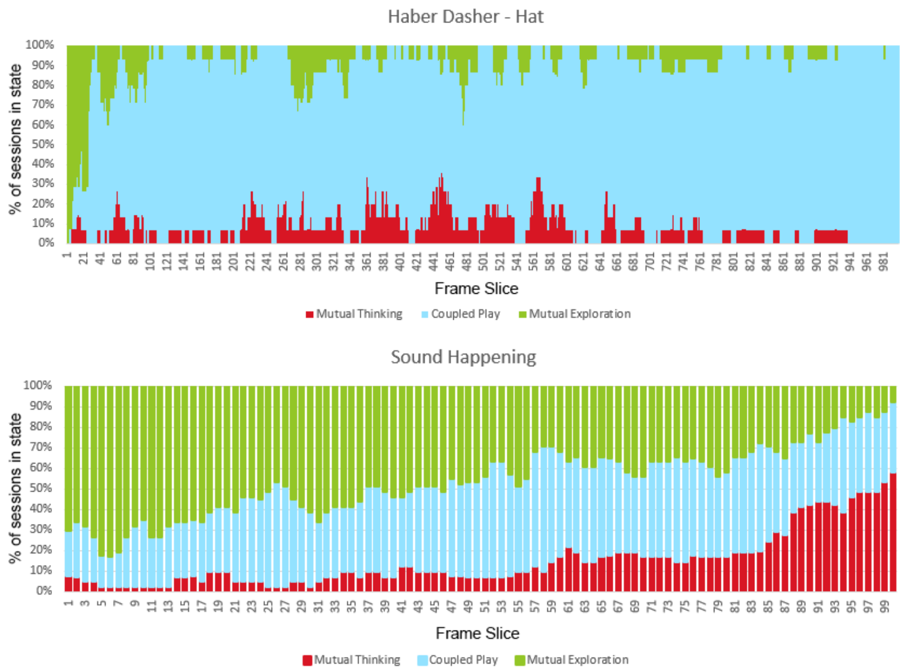

Figure 6.1: The most prevalent state charts for *Haber Dasher* and *Sound Happening* show differences in users' transition from exploration into coupled play.

For example, a designer intent on creating an experience where players are encouraged to spend a long time exploring and uncovering new controller abilities may wish to lengthen the initial state of mutual exploration, while a designer who wishes to create an experience where players perform under temporal pressure may adjust instructions or physical signifiers to reduce the length of time players spend exploring before transitioning to coupled play. This representation may also be used to highlight differences in play styles among dyads: if the length of the initial period of coupled play is highly variable, potential causes (such as variations in players' previous game expertise or any number of other factors) may be highlighted for investigation, indicating questions such as "Do frequent gamers learn how to use this controller faster than infrequent gamers?"

Prevalence of coupled play during sessions. A second component of the creative sense-making summary data that may offer insight into players' sense-making patterns with a given artifact is the prevalence of the coupled play state over the course of the summary

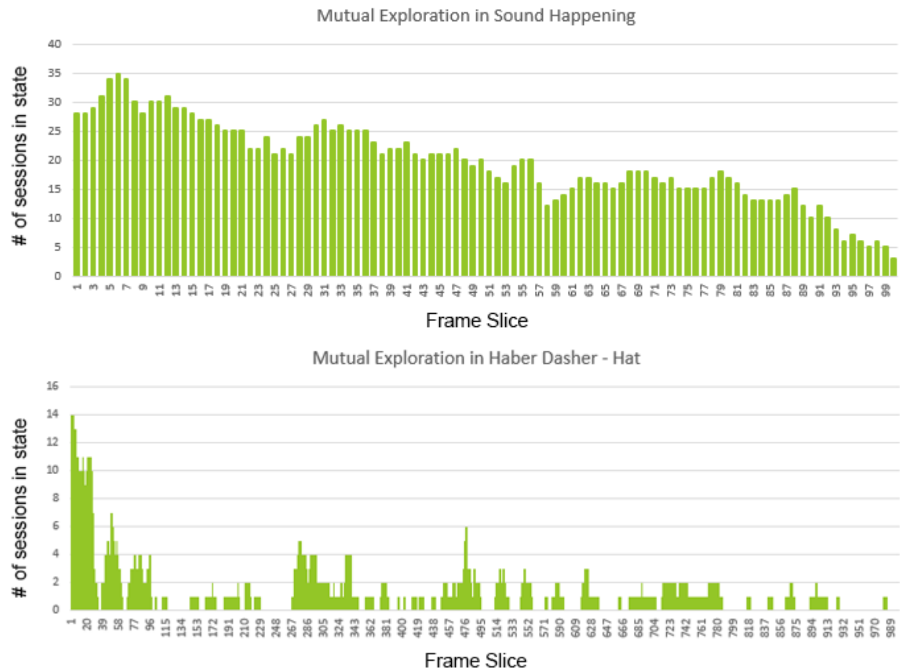

Figure 6.2: Occurrence of mutual exploration for *Haber Dasher* and *Sound Happening*.

chart. Artifacts where coupled play is strongly prevalent for large portions of sessions may indicate that players are able to confidently use the mental models developed at the beginning of their sessions. Artifacts whose sessions show coupled play in more targeted portions of sessions may indicate players refining their mental models of the artifact and controller more frequently or to a greater extent, revisiting experimentation with controllers or questioning game rules. Two disparate

From a design standpoint, the prevalence of coupled play can be used to identify and tune events, mechanics, and affordances that can prompt diversions from coupled play to shape a play experience. Long periods of coupled play in artifact sessions may indicate opportunities to introduce events, such as interruptions or the introduction of new mechanics, to prompt divergence from a state of coupled play and new experimentation among players. Such techniques can also be used to tune the total amount of coupled play during interaction and indicate where in the play-experience more variety in sense-making may be desired.

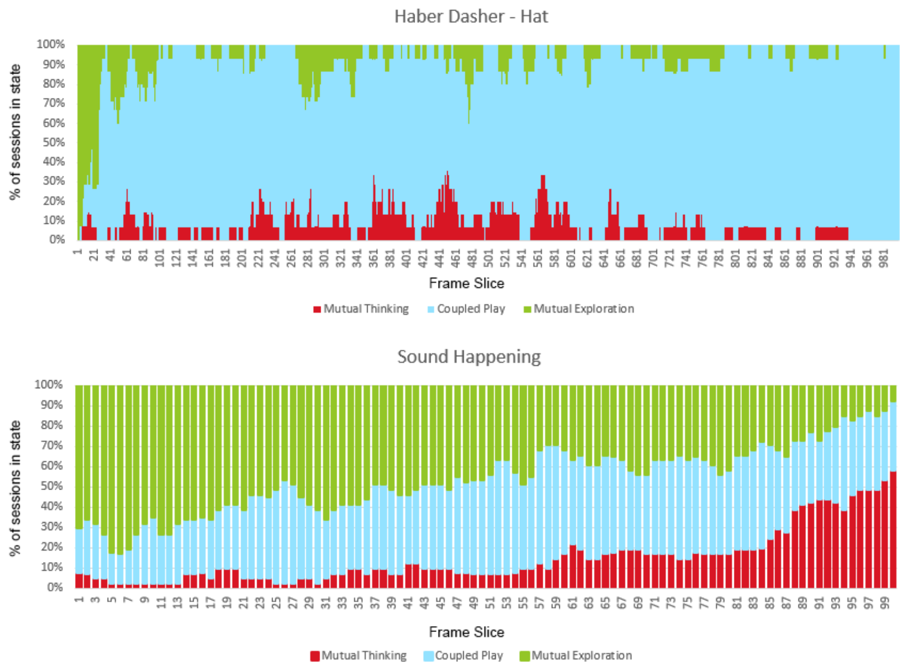

Figure 6.3: Most prevalent state for *Haber Dasher* and *Sound Happening* showing differences in the prevalence of coupled play during sessions with each

6.1.2 Shared Qualities in *Haber Dasher*

The primary identifying features of *Haber Dasher* and the hat controller include the size and shared and wearable nature of the controller, and the lightheartedness of the game's premise. The game's initial idea relied heavily on the absurdly large size of the hat, which also grew from a desire to experiment with the visibility of such a large controller.

Opportunities for deflecting embarrassment. The game fiction of *Haber Dasher* and the absurd size of the controller lends itself to players engaging nonseriously in play with the game. Players were observed laughing at themselves, the controller, the game, and the character's awkward movements, sometimes expressing mock exasperation at the avatar's clumsiness ("Zorg, please!"). The clip-on ties offered to players were chosen to further a humorous play-environment, encouraging players to laugh at themselves and be "in on the joke." Rather than asking players to engage seriously with such a ridiculous premise, *Haber Dasher* was crafted to allow players to find amusement in the game even as they play it. This allows for players to interact with the game in an ironic or joking manner, which requires less social buy-in than interacting with something seen as nonserious more earnestly.

Shared resources and responsibilities. The shared responsibility in *Haber Dasher* is straightforward - players jointly influence control of the shared avatar, and succeed or fail as a team. In the case of *Haber Dasher*, shared resources are not multiple control objects or pieces of information, but instead take the form of one singular shared resource: the hat. Because players both wear the hat on their heads and the tilt angle of the hat is used to drive the character, it is very difficult — and in some cases impossible — for a single player to move the hat to a desired angle without the cooperation of their partner. The rigidity of the hat controller further contributes to this effect: one player pushing the hat in any direction moves the other player, so coordination of motion is required for control that does not cause discomfort for one player. This rigid sharing mechanism may contribute to the large amount of coupled play seen in *Haber Dasher* sessions.

Exploratory behavior prompted by controllers and digital mechanics. Though *Haber Dasher* players were instructed on how to use the hat controller before starting to play, most dyads still engaged in a period of mutual exploration at the beginning of their sessions. Further, the periods of mutual thinking that occurred frequently after an in-game coffee spill indicate that the interruption created by the coffee spill game mechanic prompted renewed negotiations and exploration of the controller and its relationship to the game. The differences in the occurrence of mutual thinking and mutual exploration states between the hat control and gamepad control conditions (shown in Figure 6.4 and Figure 6.5) additionally suggest that controller novelty may contribute to the exploratory actions of players.

Physically defined play-space boundaries. *Haber Dasher* approaches the physical definition of the play-space in a slightly different way than *Sound Happening* or *Trip*, which both include static "set pieces" within or atop which players play. *Haber Dasher* instead uses the controller itself as the primary "set piece;" the boundaries of play can be consid-

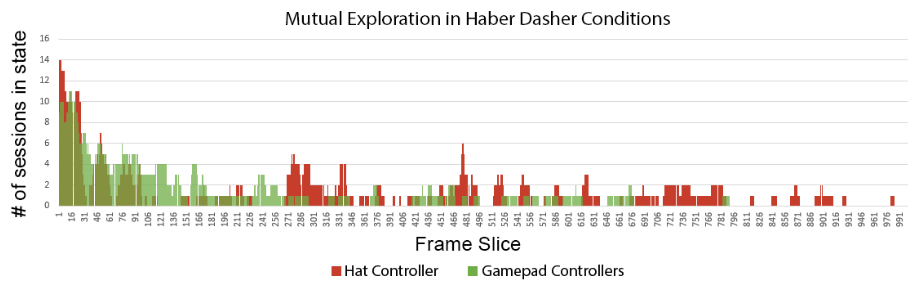

Figure 6.4: Mutual exploration occurrence in *Haber Dasher* conditions.

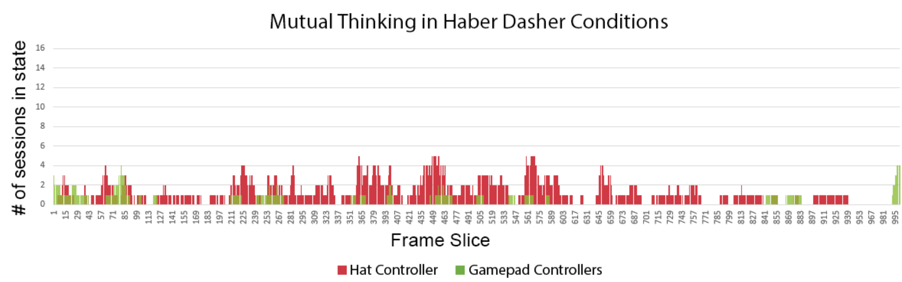

Figure 6.5: Mutual thinking occurrence in *Haber Dasher* conditions.

ered synonymous with the boundaries defined by the hat. In addition to the hat functioning as a wearable costume for players, its outer rim lies entirely outside the boundaries of players' bodies, creating a "under the hat" space only populated by the players and separating them from those "outside" the hat. This visibility is furthered by the size of the hat, which dominates the play space and literally covers players.

Duration of initial period of mutual exploration. The summary chart (shown in Figure 6.6) for most prevalent states across *Haber Dasher* sessions show a distinct emphasis on mutual exploration at the beginning of sessions, which typically transitions to another state within 33% of the session time. This pattern indicates a rapid transition from mutual exploration to coupled play or mutual thinking and shows players quickly learning the functions of the controller with little experimentation.

Prevalence of coupled play. The prevalence of coupled play across *Haber Dasher* sessions is notable primarily due to the large portion of the summary data (shown in Figure 6.7) in which more than 13 of the 15 dyads were in a state of coupled play. Part of this may

Figure 6.6: Most prevalent sense-making state per 1/1000th of session for *Haber Dasher*.

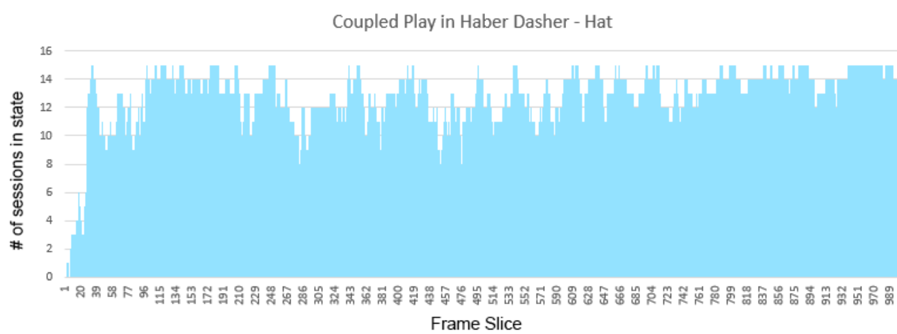

Figure 6.7: Occurrence of coupled play per 1/1000th of session for *Haber Dasher*.

be due to the simplicity of the control axes, as players were able to quickly exit the initial phase of mutual exploration. This pattern indicates that players spent the majority of play sessions engaged in fluid, skillful action with one another. During this time, players' attention was focused on achieving in-game goals together.

It is additionally worth considering whether the shared nature of the controller contributed to this effect, as the rigidity of the shared controller made it physically difficult or impossible for one player to enact in-game movements without the cooperation of their partner. This effect could indicate shared, rigid controllers as a means of facilitating close coupling in play.

6.1.3 Shared Qualities in *Sound Happening*

The design choices integrated in the version of *Sound Happening* used for this analysis centered on supporting a low interaction floor and exploration during interaction. While the base functionalities for the installation existed before the use of *Sound Happening* in this thesis, the modifications made to the system were intended to allow for additional complexity to promote exploratory play among adults while retaining the ability of the installation to respond to simple movements or actions within the play-space.

The mapping of each ball color to an instrument was retained from the original version of the installation. Rather than mapping location to singular notes, ball colors were mapped to instrumental loops with additional properties tied to balls' locations in three dimensions. Additionally, sonic modifications such as pitch distortion and tempo based upon balls' collective and relative space were chosen to encourage collaborative interaction and multi-user experimentation.

Opportunities for deflecting embarrassment. Unlike *Trip* and *Haber Dasher*, which allow for keying through humorous premises, *Sound Happening* allows for embarrassment deflection by relying on interaction that is highly similar to everyday activities (standing, holding). This reduces the social risk posed to interactors and requires no "buy-in" to game roles or game fiction. Despite the brightly colored beach balls — which may carry childish connotations — serving as the primary interface for the installation, players did not have to become heavily involved in beach-ball-based play if they did not wish to. During sessions, players were able to walk around the space, experimenting with balls by moving them or passing them to the other player, and even throwing the balls at one another playfully in an ironic keying of the interaction.

Physically defined play-space boundaries. *Sound Happening* can be configured numerous ways due to the size of the technology that runs the experience. For this thesis, it was installed in a pop-up tent. A 13-foot-by-13-foot-by-10-foot metal scaffold was additionally considered for use in the installation, but was ultimately not chosen due to logistical challenges. Both of the structures considered shared a key core property: they bound the play space in three dimensions. The scaffold and tent marked the play area's width, depth, and height, allowing for players to "enter" or "exit" play by moving into or out of the bounds of the structure. The webcam running the installation was configured to capture as much of the marked space as possible; the structure further served to delineate the bounds of the ground area in which balls could be tracked by the webcam.

Shared resources and responsibilities. *Sound Happening*'s beach balls constitute a shared resource pool themselves, but an additional resource that is also shared is the resources of space. Since *Sound Happening* is required to take place within a bounded space due to the nature of the sensor technology used to run the installation, players must share physical space as well as control of the beach ball inputs in the space. Players do not necessarily share control in the same way for beach balls knocked outside the play area, but in user sessions, one or both players often would coordinate the return of balls to the play-area or immediately adjacent space where balls were once more accessible to both players. Shared responsibility in *Sound Happening* is similar to shared responsibility in *Haber Dasher*, where two players share control over a single output. The inputs of both players (presuming each player has assumed some control over one or more balls) are used to drive the sonic output of the system. Further, some effects cannot be achieved by a single player, even if holding all three beach balls.

Exploratory behavior prompted by controllers and digital mechanics. *Sound Happening*'s multiple control mappings responds to inputs in a complex manner, which offers interactors the opportunity to experiment with a wide array of possible configurations. The mappings, which include responses to the movement of individual balls as well as all balls in the space collectively, encourages both independent and coupled experimentation. This complexity invites ongoing exploration with the installation, which is reflected in the occurrence of mutual exploration states *Sound Happening* at all parts of the sessions analyzed.

Duration of initial period of mutual exploration. In contrast to the patterns of initial mutual exploration seen in the *Haber Dasher* summary data, players interacting with *Sound Happening* exhibited stages of initial mutual exploration that were much more variable in length and much longer compared to the overall length of the session, as shown in Figure 6.2. While the largest prevalence of mutual exploration was still seen at the beginnings of play sessions, several *Sound Happening* dyads remained in a state of mutual exploration well into the session, with some dyads remaining in a state of mutual exploration at end of their sessions. A potential cause for this phenomenon is the more complex (as compared to *Haber Dasher*) control scheme offered by *Sound Happening*, which encouraged players to spend time experimenting with different actions and their outputs. *Haber Dasher* includes two (both continuous) control input mappings: the forward/backward tilt of the hat controller, and the left/right tilt of the hat controller. In contrast, *Sound Happening* offers eight control inputs: the presence or absence of each of three balls (binary), the height of each of three balls (continuous), the average distance between the balls (continuous), and the proximity of the balls' centerpoint to the center of the play-space (continuous). From a design standpoint, this phenomenon suggests that designing for distributed control of several inputs can support prolonged exploration during play by giving players more features and mappings to discover.

Prevalence of coupled play. The pattern of coupled play in *Sound Happening* sessions displays a pattern among its players that is substantially different from that seen in the goal-based artifacts. Coupled play overall appears less in the *Sound Happening* summary data; the maximum number of sessions in the state was 26 out of 41 sessions total, as opposed to 15 of 15 *Haber Dasher* sessions and 14 of 15 *Trip* sessions. This is likely due to the increased exploratory action (mutual exploration and mutual thinking) seen among *Sound Happening* dyads as they engaged with the more complex control scheme of the system.

6.1.4 Shared Qualities in *Trip*

The design choices made for *Trip* were primarily aimed at crafting an asymmetrical play experience in which both players interacted with unusual controllers and distinct abilities. Humor in the game's fiction and role-based controllers served to support collaborative play, which is amplified by the use of asymmetry to drive interreliance. The primary driving design point for *Trip* was providing the challenge to players of describing unusual-looking objects and communicating necessary information.

Opportunities for deflecting embarrassment. Like *Haber Dasher*, *Trip* utilizes a nonserious premise and additional uses unusually shaped panel objects to encourage lighthearted interaction during play. The challenge for the Driver to maintain balance while controlling the in-game ship provided a level of additional challenge that could support physically-based humor as players attempted to stay atop the balance ball. Despite fast-paced play and timed events, *Trip*'s players often exhibited amusement at the objects they needed to describe and at the challenge of navigating the asteroid field. Players' collisions with asteroids in-game and attempts to describe the unusual control panel objects frequently resulted in laughter during play.

Physically defined play-space boundaries. In designing the physical space for *Trip*, the necessity of building a platform to house the balance ball controller led to the development of platforms for both players to stand or sit atop during play. In addition to providing crucial housing for the Driver's controller and a base into which the stationary yoke could be screwed, the platforms served a game design purpose as physical markers of the play-space. At the beginning of a play session, as players step onto the platforms, they "step up" into their fictional spaceship positions, bounded by the platforms they stand upon and the controllers and screens they interact with. Further, the play-space is divided by a large black fabric divider which segments it into two spaces, one for each player. In the case of the driver, the controller itself aids in defining the play-space due to its location under the player's feet.

Shared resources and responsibilities. Unlike *Sound Happening* and *Haber Dasher*, *Trip* explicitly divides controller access between players, and augments this by dividing information access between players. The means by which resources are shared in *Trip* includes the connection between one player's controller and the other's screen (and the information presented on it).

Exploratory behavior prompted by controllers and digital mechanics. The complexity of the *Trip* controllers, combined with the highly limited information given to players at the start of sessions, may contribute to the substantial number of sessions in which players began in a state of mutual thinking (shown in Figure 6.8. Players of *Trip* often began by asking questions of one another about what they were supposed to do or what the other player was seeing.

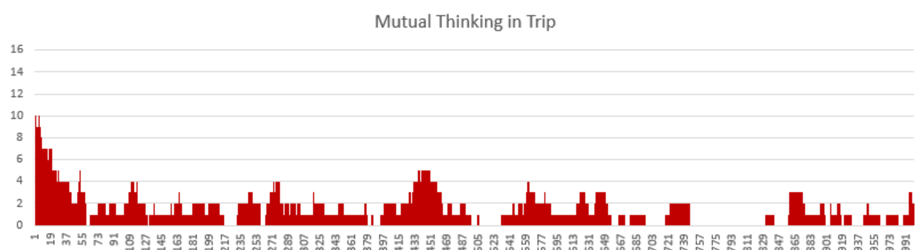

Figure 6.8: Occurrence of mutual thinking in *Trip* user sessions.

Duration of initial period of mutual exploration. The increase in the number of sessions where dyads were in a state of mutual exploration in the *Trip* data is not as dramatic as that seen in *Haber Dasher* sessions, but still reached a point where more than half of player dyads were in a state of mutual exploration within the first 10 percent of sessions (see **??**). The length of the initial periods of mutual exploration in *Trip* is also more variable. It is worth noting that many *Trip* sessions included mutual thinking near the beginning of the session, with 10 dyads starting play in a state of mutual thinking. This may be attributed to players' conversations as they worked to better understand one another's interfaces, controllers, and responsibilities.

Prevalence of coupled play. Like *Haber Dasher*, most dyads were in a state of coupled

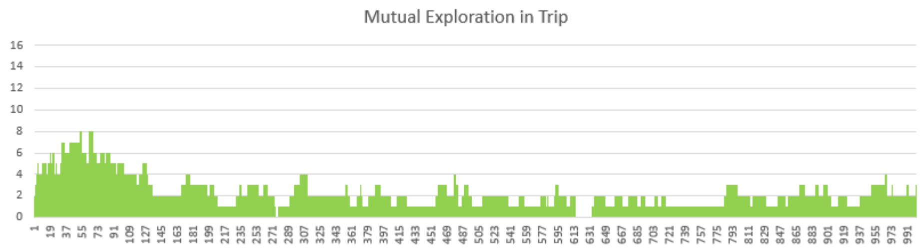

Figure 6.9: Occurrence of mutual exploration in *Trip* user sessions.

play for the majority of *Trip* sessions. While this effect is not quite as pronounced as it is in the data from *Haber Dasher*, this shared quality demonstrates dyads engaged in goal-based play spending more time in coupled play than those engaged in exploratory play like dyads interacting with *Sound Happening*.

6.2 Design Guidelines

I propose the following design guidelines for alternative control games and playful experiences based upon my findings from analysis of the alternative controllers presented in this thesis.

6.2.1 ***DG1. Promote coupled play with goals or promote exploration with open-ended play.***

The sense-making data for the goal-based artifacts (*Trip* as well as both *Haber Dasher* conditions) shows nearly all dyads in a state of coupled play for the majority of session slices. In contrast, the data from *Sound Happening* shows a much smaller percentage of dyads in coupled play during interaction sessions. This indicates a potential relationship between the inclusion of goals in an alternative-control experience and the time players spend in a state of coupled play. Game-based interactions, including those with success or failure conditions, give players a shared motivation and encourages them to engage in a coupled manner to achieve the shared goal.

Conversely, offering an open-ended play experience may be used to support more exploratory play (encompassing states of both mutual exploration and mutual thinking), where players do not experience pressure from the experience to resolve gaps in their shared mental model and thus feel more free to experiment with the controls and their mappings. Beyond play experiences designed without goals, this guideline also points to experiences with multiple, optional, and/or untimed goals as a means of encouraging exploration within game or goal-based contexts.

6.2.2 ***DG2. Prompt renegotiation of controller use with interruptions in play.***

The introduction of an interrupting event in play (such as a coffee spill event) can be used to prompt renegotiation of players' use of a controller or interface, as seen in the sense-making curves from *Haber Dasher* (Two session curves, shown in Figure 6.10 and Figure 6.11, illustrate this effect). After the moment of interruption, players must revisit their individual and shared mental models of the controller and game-world. Interruptions can invite renewed investigation of the controller and its functionality by prompting players to transition out of a state of coupled play and into a state of mutual thinking or mutual exploration. While interruptions in the *Haber Dasher* session data were followed by periods of mutual thinking, it is likely that transitions to states of mutual exploration may also be supported; the design of interruptions to prompt transitions to specific sense-making states is an area for future inquiry.

Interruptions can be used to prompt players' consideration of the working of the controller or could be used in designs whose controllers have multiple modes or functionalities. Creating a point where players are moved out of a state of coupled play and into a period of hypothesizing and experimentation can be utilized as a technique for prompting investigation of new or changed properties of a control scheme. In situations where adjustment to expanded or changed controls may cause frustration, the introduction of an interrupting event can be used to transition players back into a state of exploration in a way that may create a smoother shift.

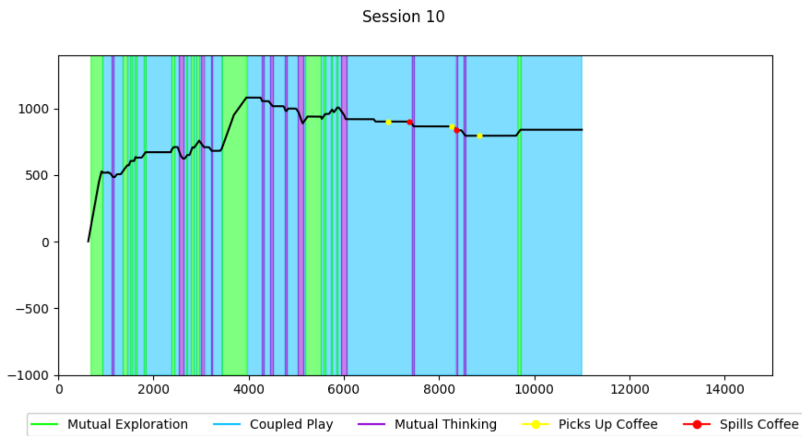

Figure 6.10: Creative trajectory curve for a dyad in the *Haber Dasher* hat condition with mutual thinking following coffee spills.

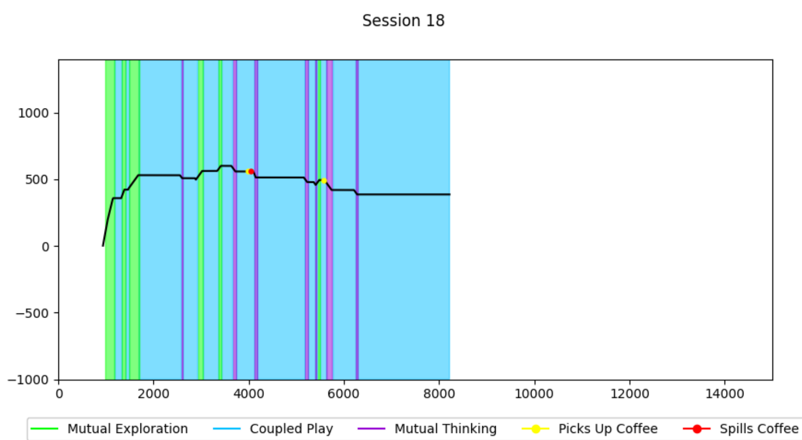

Figure 6.11: Creative trajectory curve for a dyad in the *Haber Dasher* hat condition with mutual thinking following a coffee spill.

6.2.3 ***DG3. Encourage exploration after interruptions with novelty.***

The novelty of a controller may also promote renegotiation after an interruption. The more frequent occurrence of mutual thinking and mutual exploration in sessions where players used the *Haber Dasher* hat controller compared to sessions in which players used gamepads illustrates this principle, which can be further supported by the frequency of mutual thinking periods following coffee spills in each condition. In the hat controller condition, coffee spills occurred 21 times in the 15 sessions analyzed. 19 of these spills were followed by a period of mutual thinking. In the gamepad controller condition, coffee spills occurred 16 times the 15 sessions analyzed, of which only seven were followed by a period of mutual thinking **or** mutual exploration. Figure 6.12 and Figure 6.13 show the sense-making curves for *Haber Dasher* dyads that spilled their coffee four times; Figure 6.12 shows the creative trajectory of a dyad using the hat controller, while Figure 6.13 shows the creative trajectory of a dyad using gamepad controllers. The curve in Figure 6.12 shows a period of mutual thinking after each of the four spills, while the curve in Figure 6.13 shows only two of four spills followed by mutual thinking. This pattern, combined with state occurrence data for both conditions (illustrated in Figure 6.4 and Figure 6.5), indicate that a controller that is less familiar to players may prompt renegotiation after interruptions more frequently: dyads in the hat controller condition were in mutual exploration and mutual thinking states more frequently during the middle portions of their sessions than those using gamepad controllers.

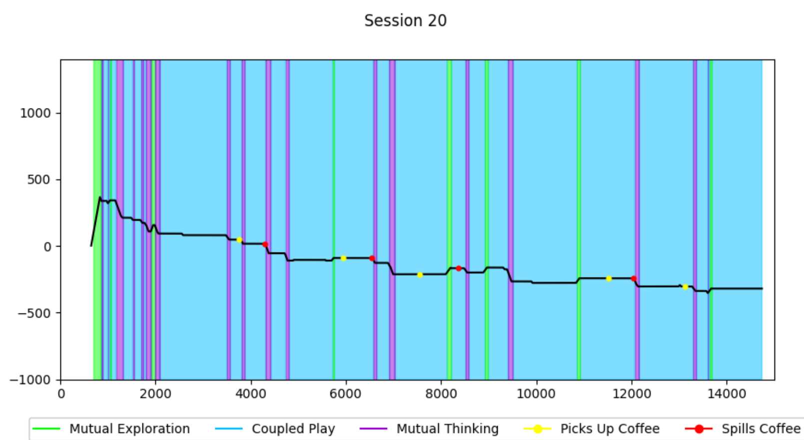

Figure 6.12: Creative trajectory curve for a dyad in the *Haber Dasher* hat condition with four coffee spills.

6.2.4 ***DG4. Encourage exploration with multiple axes of control and/or distributed controls.***

The longer periods of mutual exploration seen in *Sound Happening* as players worked to investigate sonic outputs from different ball positions compared to the shorter periods of mutual exploration in *Haber Dasher* indicate that there may be a relationship between

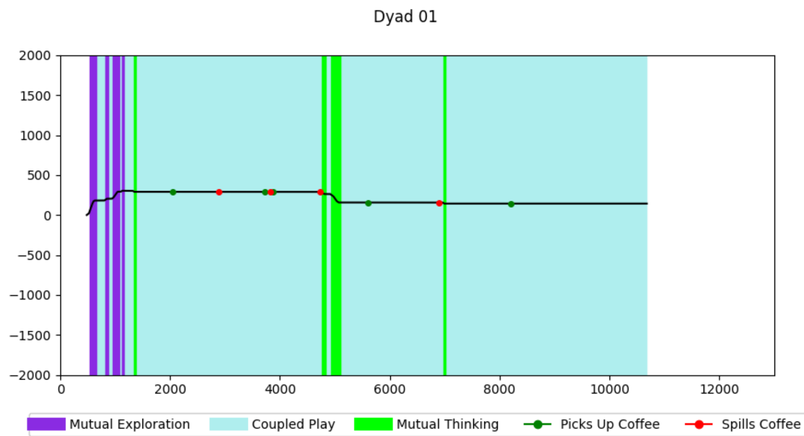

Figure 6.13: Creative trajectory curve for a dyad in the *Haber Dasher* gamepad condition with four coffee spills.

the number of mapping axes and the length of mutual exploration as compared to session length. This is further supported by the state occurrence data from *Trip* player sessions, which — like *Sound Happening* sessions — included dyads in mutual thinking for almost all session slices, including slices near and at session end. Conversely, the occurrence of mutual exploration in *Haber Dasher* sessions is much sparser, which may be due to players learning to use the simple controller rapidly near the beginning of their sessions. Though the goal-based nature of *Haber Dasher* may contribute to this pattern in that goals may aid in promoting coupled play, it is worth noting that dyads playing *Trip*, which is also goal-based but includes a greater number of control axes, show a great deal more mutual exploration and mutual thinking than those playing *Haber Dasher*.

Relationships can also be seen in the creative sense-making data between the distribution of control components among players and the speeds at which dyads transition into coupled play after their initial periods of mutual exploration or mutual thinking. This can be visualized in relation to the interreliance theme, where the transition to coupled play takes longer as players' controls move from asymmetrical-independent to symmetrical-shared (as illustrated in Figure 6.14). This suggests that players who manipulate control objects jointly may transition faster into coupled play; conversely, players who manipulate separate components of the control system take longer to transition to this state.

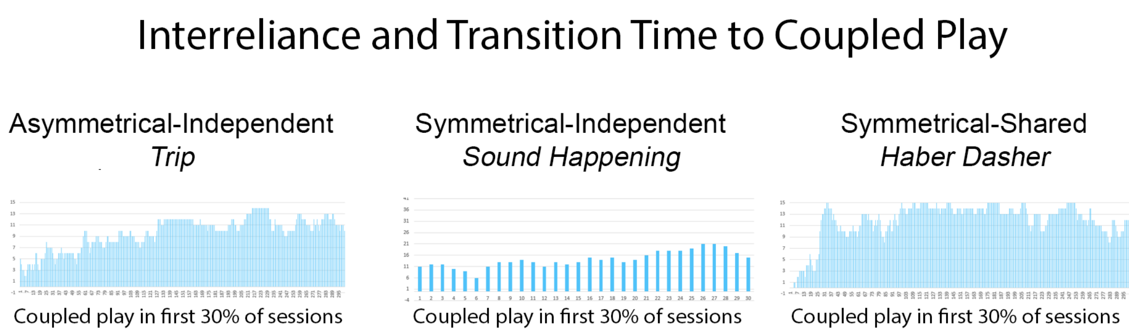

Figure 6.14: Coupled play in the first 30% of sessions and interreliance classification.

6.2.5 *DG5. Focus information exchange or coupled action by tuning shared attention.*

A component of design not covered by the taxonomy described in Chapter 3 that is also reflected in the creative sense-making data is the sharing or distribution of interactor attention facilitated by the artifacts and controllers. Players' visual attention can be focused on a screen or other singular external display or output, on multiple screens or outputs, or on one another. This can be directed by the use of game mechanics and space and controller design [43]. As an example, *Haber Dasher* physically focuses players on their shared on-screen output: not only do players see the game on one large screen, but the design and placement of the hat facilitates players facing the same direction during play, further directing their attention towards the game display. Conversely, *Sound Happening* distributes interactor attention among the other people and objects in the play-space and auditory output.

Artifacts that directed players' attention towards a singular output exhibited a greater amount of coupled action (which includes both coupled play and mutual exploration). Multiple studies have highlighted shared gaze as a tool to enhance collaborative action [72, 73, 74, 75], which further supports the notion of a relationship between shared gaze and shared attention and coupled play.

In contrast, dyads using artifacts that prompted players to direct their attention to separate or multi-sensory outputs engaged in greater amounts of mutual thinking. This is likely a result of players needing to share or exchange more information with one another than they do while using artifacts with singular, shared outputs, where both can immediately see the result of their coupled action.

CHAPTER 7

DISCUSSION AND FUTURE WORK

This thesis presents three themes for collaborative controller development, outlines the design of three artifacts using the three themes, and analyzes player actions with the controllers using creative sense-making. Guided by the three themes and taxonomy drawn from the literature, I developed three alternative-control playful artifacts to investigate the use of creative sense-making as a means of describing players' actions during play sessions. The use of creative sense-making analysis as an augmentation to other forms of knowledge enables the visualization of and reflection on the relationship between controllers' physical properties and players' social cognition, which can be used to support the development of design guidelines for collaborative controllers.

The five guidelines developed using this method are presented to guide the development of future works in this space. While the three artifacts outlined in this thesis occupy a small portion of the very large design space available for alternative controllers, their location at the boundary points of the space allows for their design to prompt valuable reflection on the relationships between controllers, game mechanics, and play. The contributions made by this thesis have the potential to support design and evaluation practices across numerous games, tangible interface, and human-computer interaction fields. In addition to the designed artifacts serving as exemplars in their own right, the use of creative sense-making to examine patterns of joint activity during play expands the documented uses of the framework, supporting future use in understanding embodied collaborative play in both goal-based and non-goal-based settings.

7.1 Limitations and Future Work

The use of creative sense-making to investigate dyadic play is not meant to replace existing methodologies for evaluating designs or describing play. Creative sense-making is apt for representing the processes by which players learn about their environment, their controllers, and one another, but is limited to covering the sense-making aspect of the interaction. The framework does not account for player enjoyment, social closeness, or lengthier interactions beyond players figuring out how to use a controller to reach their goals. I recommend the use of creative sense-making analysis as an augmentation to other techniques for evaluating interactions, as sense-making curves and summary curves can support knowledge gained from a broader set of techniques. I have used this analysis in this way, supplementing means of generating design knowledge, such as artifacts, design journals, and annotated portfolios.

This work also provides a foundation for further research on the use of creative sense-making in tandem with other evaluation and knowledge-making techniques. In addition to further investigation of the relationship between creative sense-making and in-game events (such as the periods of mutual thinking that followed coffee spills in *Haber Dasher*), there is strong potential for creative sense-making trajectory curves and summary charts to augment metrics such as enjoyment, social closeness, and immersion. There is further opportunity to investigate creative sense-making patterns that mark boundaries of the patterns seen for an artifact. The sense-making activties of "extreme" player dyads are a rich space for further investigation. Finally, investigation of single-player sense-making curves as an additional dimension of analysis using the existing technique to investigate patterns such as leader/follower dynamics is an area of interest for future work.

Furthermore, creative sense-making has only been used to explore dyadic interactions and has not been used to investigate embodied collaboration within larger groups, which introduce broader, more complex social and cognitive dynamics that are too large in scope to be covered in this thesis. The adaptation of the framework for use in groups of three or more is a rich space for future exploration, and I intend to explore this trajectory in my research in the coming years, particularly because the flexibility of alternative controllers allows for design to support larger numbers of players.

The boundary artifacts developed for this thesis are useful in describing the edges of the alternative controller space, but do not completely cover the large variety of controllers that are possibly covered by this space and taxonomy. As practitioners continue to experiment with controller properties, it is likely this taxonomy will require expansion and additional detail to cover more cases. The future development and subsequent analysis of additional alternative controllers covering other parts of the design space may help to provide additional detail and information about the relationships between physical affordance and players' sense-making activities.

7.2 Revisiting Research Questions

In this section, I revisit the research questions posed to guide this thesis, and outline the outputs and contributions resulting from each. In the following section, I highlight four primary contributions of this work in greater detail.

- **RQ1:** How does creative sense-making play a part in how people collaborate in embodied collaborative play?
  - RQ1.1: Can creative sense-making states be used to describe actions in embodied collaborative play?
    - **Outputs:** Creative sense-making codebooks for video data of interactions with each artifact/condition.
    - **Contributions:** First recorded use of creative sense-making to describe gameplay with alternative controllers; addition of four analyses to the body of documented uses of the framework as an analysis tool.

        * **Limitations and Future Work:** Application is still currently limited to dyadic play; future work may expand uses to groups of 3 or more.

    - RQ1.2: Can patterns of creative sense-making be discerned from analysis of embodied collaborative play?

        * **Outputs:** Creative sense-making curves for all sessions quantifying and describing collaborative sense-making trajectories; description of observable patterns within/across artifacts/conditions.

        * **Contributions:** Descriptions of sense-making during play with three alternative-control artifacts; two novel methods for aggregating and visualizing creative sense-making data for all sessions with an artifact.

        * **Limitations and Future Work:** Three artifacts offer good, but not exhaustive, coverage of design space; future work may seek to expand creative sense-making analysis to other artifacts with other combinations of affordances.

- **RQ2:** How do the physical affordances of alternative controllers correlate to features of the creative sense-making experiences of players?

    - RQ2.1: Can creative sense-making patterns from embodied collaborative play sessions be mapped to the physical affordances of the controller used?

        * **Outputs:** Creative sense-making descriptions of differences in patterns of collaborative play with traditional versus alternative control conditions.

        * **Contributions:** Summary charts showing distinct differences in sense-making patterns between dyads using alternative vs. traditional controllers for the same game.

        * **Limitations and Future Work:** Only applied to alternative- and traditional-control versions of one game; future work may explore differences in using

various alternative controllers with the same game and/or different games with the same alternative controller.

- RQ2.2: Do generalized creative sense-making curves from embodied collaborative play sessions with different alternative controllers exhibit different properties?

  * **Outputs:** Creative sense-making descriptions of differences in patterns of collaborative play with alternative controllers with varying physical affordances.

  * **Contributions:** Summary charts showing distinctly different patterns of collaboration among players of alternative-control games with varying affordances and properties.

  * **Limitations and Future Work:** Some patterns are discernible, but future work with additional controllers is required to confirm the existence of patterns correlated to physical affordances.

- **RQ3:** How can creative sense-making analysis of play with collaborative alternative controllers yield generalizable knowledge for the design of other artifacts of the same type?

  - RQ3.1: Can observed events in embodied collaborative play sessions be mapped to creative sense-making states or changes in creative sense-making states during an embodied collaborative play session?

    * **Outputs:** Descriptions of interplay between play-events and sense-making processes of players.

    * **Contributions:** Connection of in-game interruptions to change in sense-making state.

    * **Limitations and Future Work:** Pattern visible in *Haber Dasher* sessions

but not *Trip* sessions; future work required to confirm relationship and investigate potential prerequisite conditions for effect to occur.

- RQ3.2: What design guidelines can be developed for the creation of alternative controllers that promote patterns of creative sense-making?
    - **Outputs:** Series of design guidelines for developing alternative-control games and playful experiences.
    - **Contributions:** Five design guidelines for collaborative alternative controllers based upon boundary artifact designs and sense-making analysis of play with artifacts.
    - **Limitations and Future Work:** Future work may explore validation of design guidelines with alternative controller developers.

7.3 Contributions

7.3.1 Three Themes and Taxonomy for Design Generation

The three themes for collaborative controllers — and the accompanying taxonomy — proposed in Chapter 3 prove useful in the generative part of the design process, demonstrated by their support of crafting the three boundary objects outlined in this thesis. In approaching the design of the three artifacts discussed, I sought to craft three games and controllers that approached the three themes for collaborative controllers in highly disparate ways, at once defining the design space and exploring the particularities of the objects at its edges. The themes proved useful in supporting the generation of new and modified designs for alternative controllers, prompting designed responses to the question of ways to support safety, social spaces, and interreliance [76].

7.3.2 Designed Artifacts Addressing Three Themes

Gaver argues that designed artifacts themselves can be considered to stand as research contributions in their own right, as particular exemplars of designers' judgment and foci when approaching a particular problem or challenge [20]. *Haber Dasher*, *Sound Happening*, and *Trip* are existing, interactive representations of design knowledge being brought to bear on particular situations through the lenses of safety, social spaces, and interreliance. These artifacts can be considered distinct points in the design space for alternative controllers, defining new boundary points within it.

7.3.3 Use of Creative Sense-Making to Analyze Gameplay

This thesis marks the first use of creative sense-making to examine social and cognitive patterns in goal-based play **(RQ1, RQ1.1, RQ1.2)**. The resultant sense-making curves and summary charts depicting state prevalence during play sessions shown in in Chapter 5 offer novel methods of understanding the social processes involved in embodied play. Despite the limited scope of this work, the information provided by creative sense-making analysis has proved useful in illustrating the social-cognitive patterns of players over the course of play sessions. The distinct shifts in dyads' sense-making states as seen in the analysis for each artifact indicates the potential for creative sense-making data to offer a robust means of describing collaborative playful interaction.

The summary charts describing joint sense-making state prevalence and occurrence as related to session progress mark a novel contribution in the field of creative sense-making analysis, and offer an additional means of using the framework to analyze collaborative embodied play across multiple sessions. The summary charts produced for the artifacts in this thesis describe play sessions with unique qualities, which are made clearly visible by this means of summarizing the data. Patterns in physical exploration, questioning, and tightly coupled play are distinctly visible for each artifact.

7.3.4 Documentation of relationship between game and controller design and players' creative sense-making activities

The analysis of three alternative-control artifacts (and a contrasting traditionally-controlled version of an artifact) has allowed for the examination of the relationship between the physical affordances of controllers and the sense-making activities of interactors **(RQ2, RQ2.1, RQ2.2, RQ3.1)**. The sense-making properties enumerated for each artifact draw from the patterns seen in both the creative trajectory curves for individual dyads as well as aggregated state occurrence and prevalence information for each artifact. Several properties of sense-making curves and aggregate data can be mapped to points in the three themes taxonomy or to other design decisions made (such as the coffee spill mechanic in *Haber Dasher*. The relation of design choices and taxonomic positions to sense-making outcomes can be used to highlight opportunities to design physical properties of controllers to support certain types of sense-making behavior (for example, the use of varying approaches to designing for interreliance to support differing levels of coupled play). This process allowed for the development of the design guidelines presented in Chapter 6 and highlights additional points of interest for future work.

7.3.5 Design Guidelines for Collaborative Controllers

The design guidelines presented in Chapter 6 serve as intermediate-level design knowledge [77] that can be used in a generative capacity for designers of future collaborative controllers **(RQ3, RQ3.2)**. Each of the guidelines draws from the patterns and accounts of embodied collaborative play generated by the analysis of play sessions using the creative sense-making framework. Rather than prescribing best practices or particular courses of action, the design guidelines presented in this thesis are intended to inform design choices based upon designers' intention to support particular kinds of collaboration in play. For example, DG1 proposes a relationship between goals and coupled play: a designer who wishes to encourage both independent and paired exploration would make use of this information differently than one who wished for players to spend large amounts of time in a state of coupled play. These guidelines have been designed to serve as intermediate-level design knowledge which is more general than recommendations for specific instances and able to aid in the generation of new artifacts within the same or similar design space as those presented here [78].

7.4 Broader Contributions

The work and findings presented in this thesis exist at the intersection of tangible interface design for collaboration, design for games and play, and the design of alternative controllers, and thus offer broader contributions within these fields.

7.4.1 Collaborative Tangible Interface Design

The use of creative sense-making as a means of understanding learning and collaboration in dyadic usage of tangible and embodied interfaces can be extended beyond playful settings into applications such as tangible collaborative work interfaces and museum installations. The design guidelines produced as a result of this thesis work are targeted towards play-based embodied collaboration, but many components of the guidelines are applicable outside playful interaction. For example, DGs 1 and 2 offer recommendations for promoting either tightly coupled interaction or exploration, which can form a key component of designing for collaborative work in different settings. Interfaces that seek to facilitate efficient goal-directed work may be designed with fewer axes of control and points of interruption than interfaces for settings in which greater amounts of creative exploration are desired (for example, at the early or ideation stages of a project or in an informal learning setting where designers wish to encourage users to try a wide variety of control configurations).

The use of the creative sense-making framework as a means of describing the processes by which interactors learn to use and build a mental model of an interface is also broadly applicable outside of play-based embodied interaction. The creative sense-making analysis of the artifacts included here augments Davis et al.'s use of the framework in collaborative pretend play and sketching settings [18]. This addition further emphasizes the utility of the framework as tool for understanding collaboration in embodied play, work, and creative settings beyond gameplay.

7.4.2 Collaborative Game Design

The descriptions of the design themes in Chapter 3 include multiple mentions of alternative controllers as a means of extending and emphasizing collaborative principles that are possible to achieve using game mechanics in games that use traditional controllers. This is especially true for methods for creating interreliance in play: some of these, such as asymmetry, have already been studied in this manner [52]. The games developed for this thesis (*Haber Dasher* and *Trip*) can be considered two additions to the existing body of work in collaborative games. These games may serve future developers by offering new examples of approaches for designing for collaboration in play in both embodied and digital settings.

Play with "traditional" digital games still includes embodied interaction that allows for the application of creative sense-making analysis. While it is necessary to account for the fact that actions within these settings are not primarily oriented around learning to use an unfamiliar interface, the core principles that define individual and joint sense-making states can still be applied. Davis' use of creative sense-making in collaborative sketching provides a template for such a use; interactors used a physical interface to interact in digital space, with a substantial component of the activity (the actual drawing platform) occurring in digital space, not unlike the way a game player uses a controller interface to complete goal in a virtual setting. It is also possible that such an analysis could be applied by considering actions in-game (e.g., avatar motion or experimentation with mechanics) as "physical" unclamp events, where a player works to generate and test hypotheses virtually. Whether such a technique is a valid means of describing virtual play remains to be seen and is a rich space for further research.

7.4.3 Alternative Controller Design for Adaptive Controllers

A final application of work on alternative controller design and guidelines is the design of alternative controllers aimed at making gaming and play accessible to interactors with disabilities. The XBox Adaptive Controller has gained attention in recent years as a means of creating controllers with a wide variety of physical properties that support interaction for players with various disabilities that make manipulating traditional gamepad or keyboard controllers difficult or impossible [79, 80]. As technologies that support novel controller configurations become more varied and accessible to consumers, hobbyists, and developers, it is reasonable to expect that development of additional controllers and other input devices will occur. The themes and guideliens for controller design offered as part of this work could be applied to work in adaptive and accessible controller development, particularly that which focuses using the physical affordances of designed controllers to amplify or highlight game mechanics and other playful interactions (such as asymmetrical abilities reflected in controllers or costume-based inputs to highlight players' game roles).

Appendices

APPENDIX A

HABER DASHER HAT CONTROL CODEBOOK

The creative sense-making codebook for *Haber Dasher* sessions using the two-player bowler hat controller appears on the following page.

Full Physical Unclamp **EXPLORING**	**Physical** • Physical exploration of controller • Moving game control (with no set hypotheses stated/hinted beforehand) • Stepping out from under hat **Language** • "How do we move in this direction?" • "What does this do?" • "Can you [tilt, rotate, lift] that way?" (but did not state/hint why they want partner to move in that direction)
Partial Physical Unclamp **EXPERIMENTING**	**Physical** • Testing hypotheses while moving hat • Pointing at screen **Language** • Goal negotiations with partner • Moving hat while generating hypotheses/making observations • "If you... we might be able to . . . " while moving • "Let's ___ to see if he will ___" while moving • "Maybe we should ____" while moving hat
Clamp **ACTING**	**Physical** • Actions follow a set pattern • Little/no hesitation • Players are coordinated • Copying or following partner's actions **Language** • Language of intent • Fluid explanation/elaborating current trajectory • Directional utterances: "let's turn right here" while moving in same direction
Partial Perceptual Unclamp **THINKING**	**Physical** • Hypothesizing/stating observations aloud, but not moving hat • Confused expression or body language (shoulder shrug, squinted eyes, hesitation) • Taking partner's direction while partner tests hypotheses **Language** • May include idle chat while attentively monitoring game/avatar movement • "How?" "What?" "Why?" • "I think ___" (without moving hat)
Full Perceptual Unclamp **DISENGAGED**	**Physical** • Fully distracted/disengaged from the game • No longer wearing/touching the hat • Off-camera **Language** • Discussing irrelevant topics (Extradiegetic communication) • Complete silence (while not clamping)

APPENDIX B

SOUND HAPPENING CODEBOOK

Full Physical Unclamp **EXPLORING /GATHERING**	• Moving balls into/out of space • Moving balls around space without discernable hypothesis while paying attention to sound • Open-ended interaction without clear intent
Partial Physical Unclamp **TESTING**	• Testing hypotheses (implied or stated) • Recruiting partner to test something or perform an action • Repeated actions with included listening for same/different sound output
Clamp **ACTING**	• Moving balls according to mental model (intentional/"educated" movement of balls) • Coordinated interactions with other player (volleying, passing, etc.) while listening to/reacting to sonic output
Partial Perceptual Unclamp **OBSERVING**	• Paused • Watching others • Observing installation's reaction • Standing still while still observing actions in the space (watchful waiting)
Full Perceptual Unclamp **DISENGAGED**	• Playing with balls with no regard for sound (e.g., throwing at one another) • Disengaged • Off-camera

APPENDIX C

TRIP CODEBOOK

Full Physical Unclamp **EXPLORING**	**Physical** • Physical exploration of controller • Interacting with controller with no set hypotheses stated/hinted beforehand or perceptible mental model of functionality • Player tries inputs to see what they do (e.g., tilting/twisting balance ball, pressing random buttons on control panel) • Player's primary focus is on trying inputs they do not have a hypothesis/mental model of **Language** • "What does this do?" while interacting with controller • "What happens if we/I...?" • "Try ____" (without stating hypothesis)
Partial Physical Unclamp **EXPERIMENTING**	**Physical** • Testing/stating hypotheses while interacting with controller • Doing what partner says to do with an explicit understanding that the effects are unknown/unclear • Experimentation with controller with clear/stated hypothesis • Player tries inputs to determine if their mental model is correct/accurate • Player's primary focus is on verifying correctness of hypothesis **Language** • Goal negotiations with partner • Interacting with controller while generating hypotheses/making observations • "I think I need to_____..." while interacting with controller • "Let me try ___ to see if ___" while interacting with controller

Clamp **ACTING**	**Physical** • Physical actions follow player's stated or implied in-game intention with an explicit (not necessarily correct) understanding/model of the effects of the action • Player acts out in-game intentions confidently and skillfully • Player manipulates controller in coordination with mental model of control functionality • Player's primary focus is achieving in-game goals **Language** • Language of intent • "Go left, left, left" or "go right!" • "Press the one that looks like _____!" • Fluid explanation/elaborating current trajectory • "Okay, go right a little more" • "It kind of looks like..."(elaborating description of controller object)
Partial Perceptual Unclamp **THINKING/ OBSERVING/ REFINING**	**Physical** • Hypothesizing/stating observations aloud • Listening to partner describe their screen/controller • Confused expression or body language (shoulder shrug, squinted eyes, hesitation) while watching screen or waiting for partner • Asking partner to try something with partner's controller • Observing game output while partner tests hypotheses or experiments • Player's primary focus is on listening to partner or observing the game-world **Language** • Asking partner questions • Observing outcomes of partner actions (e.g., after having asked partner to try something) • "How?" "What?" "Why" • "I think..." • Questions or hypotheses about how controllers work or interact ("I think you have to ____") • "Can you try ____?" "What does it do if you _____?"
Full Perceptual Unclamp **DISENGAGED**	**Physical** • Fully distracted/disengaged from the game • Not looking at screen or controller • Off-camera • Player's focus is not on anything related to the game **Language** • Discussing irrelevant topics (extradiegetic communication)

APPENDIX D

HABER DASHER GAMEPAD CODEBOOK

Full Physical Unclamp **EXPLORING**	**Physical** • Physical exploration of controller/joysticks • Moving joystick with no set hypotheses stated/hinted beforehand or perceptible mental model of functionality • Player tries inputs to see what they do • Player's primary focus is on trying inputs they do not have a hypothesis/mental model of • Building hypotheses about controller function **Language** • "What does this do?" while moving joystick • "What happens if we...?" • "Can you [tilt, rotate, lift] that way?" (but did not state/hint why they want partner to move in that direction) • "Try ___" (without stating hypothesis)
Partial Physical Unclamp **EXPERIMENTING**	**Physical** • Testing/stating hypotheses while moving joystick • Experimentation with controller/joystick with clear/stated hypothesis • Player tries inputs to determine if their mental model is correct/accurate • Player's primary focus is on verifying correctness of hypothesis **Language** • Goal negotiations with partner • Moving joystick while generating hypotheses/making observations • "If you... we might be able to..." while moving • "Let's ___ to see if he will ___" while moving • "Maybe we need to ____" while moving joystick

Clamp **ACTING**	**Physical** • Physical actions/joystick motion follow player's stated or implied in-game intention • Player acts out in-game intentions confidently and skillfully • Player moves joysticks in coordination with mental model of control functionality • Player's primary focus is achieving in-game goals **Language** • May include idle chat while controlling avatar movement • Language of intent (ex. "Go left so we can get around the corner") • Fluid explanation/elaborating current trajectory (ex. "Ok to ... we need to ... so we can ...", "Let's go forward") • Directional utterances: "let's turn right here" while moving joysticks in same direction
Partial Perceptual Unclamp **THINKING**	**Physical** • Hypothesizing/stating observations aloud, without moving joystick • Confused expression or body language (shoulder shrug, squinted eyes, hesitation) while watching screen or partner • Taking partner's direction while partner tests hypotheses • Observing game output while partner tests hypotheses • Player's primary focus is on listening to partner or observing the game-world **Language** • May include idle chat while attentively monitoring game/avatar movement • "How?" "What?" "Why?" • "I think . . . " (without moving joysticks) • Questions or hypotheses about rules of game-world ("I don't think we can go in the alleys")
Full Perceptual Unclamp **DISENGAGED**	**Physical** • Fully distracted/disengaged from the game • Hands off controller • Off-camera • Player's focus is not on anything related to the game **Language** • Discussing irrelevant topics (Extradiegetic communication) • Complete silence (while not clamping)

APPENDIX E

HABER DASHER HAT CONTROL CREATIVE TRAJECTORY CURVES

Frame numbers appear on the horizontal axis, and the cumulative integral sum for both players is plotted on the vertical axis. Events where players pick up a cup of coffee are plotted in yellow. Events where players spill their avatar's coffee are plotted in red.

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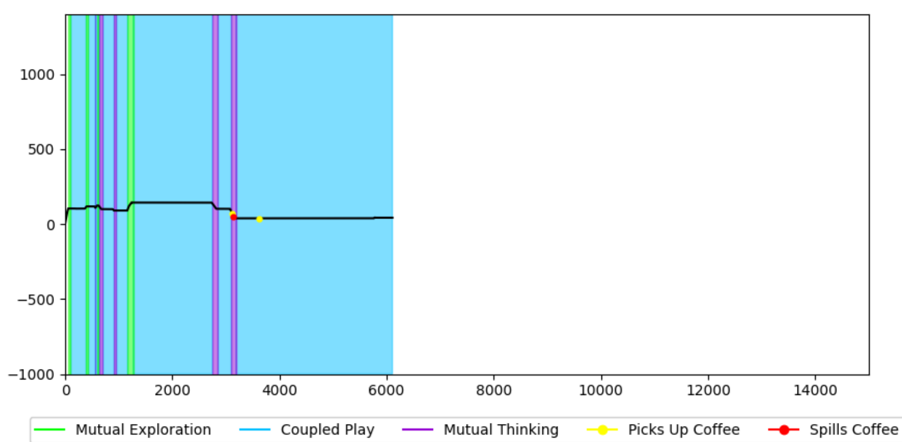

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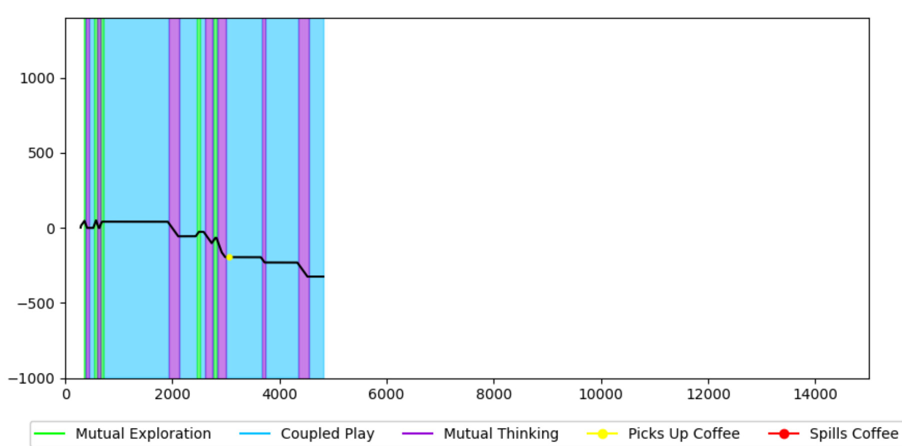

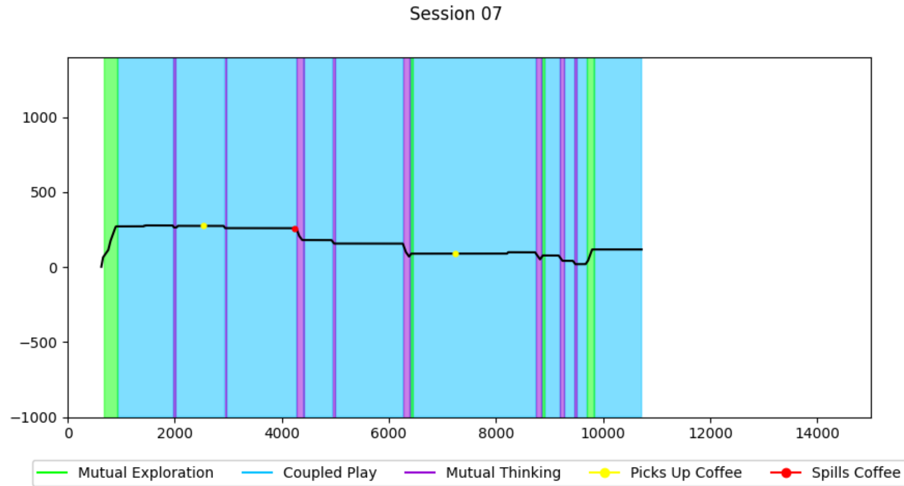
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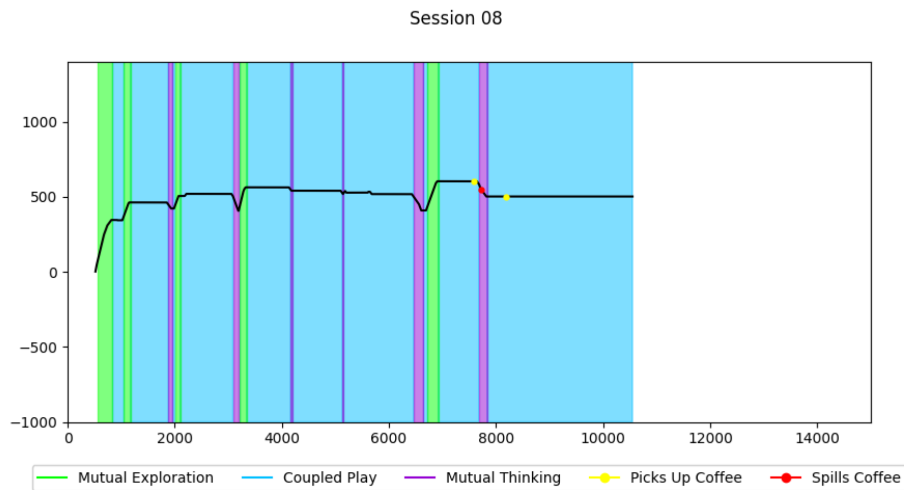
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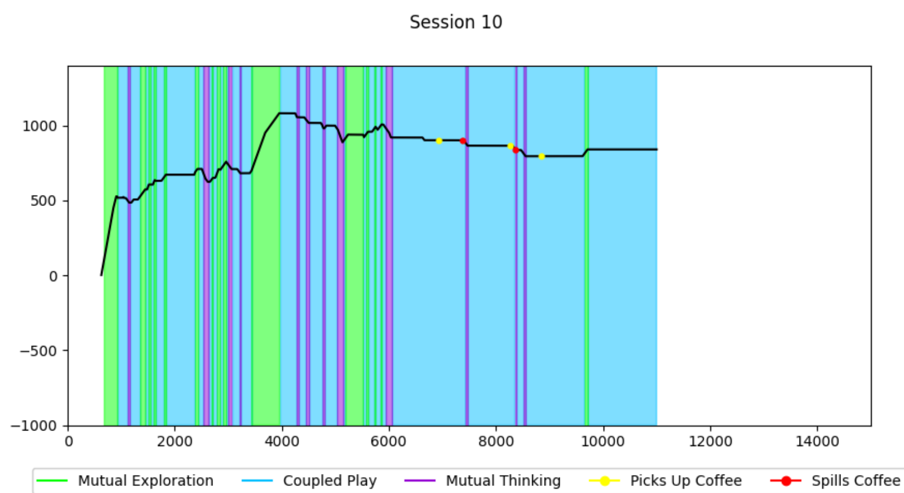
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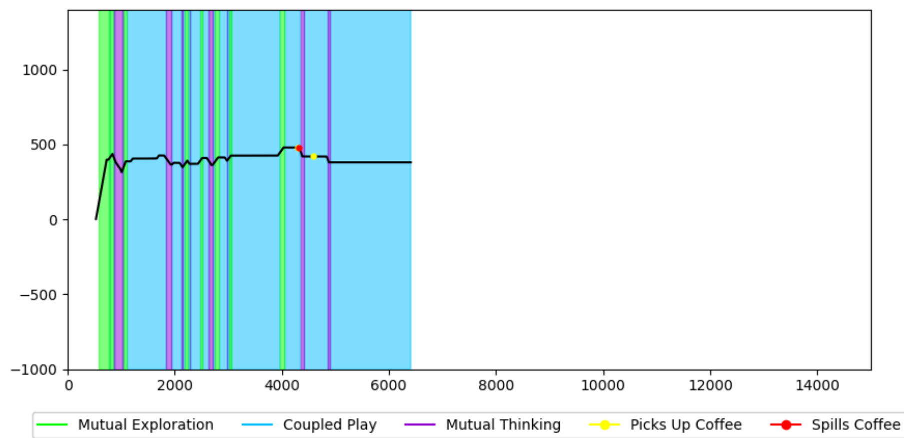

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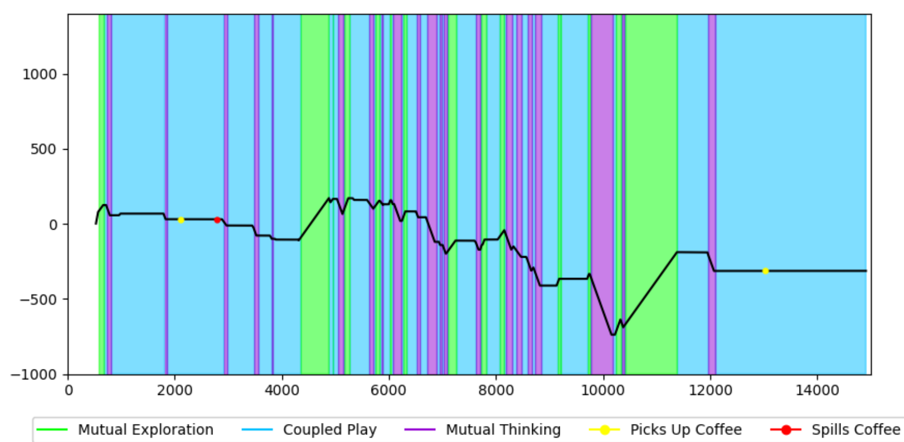

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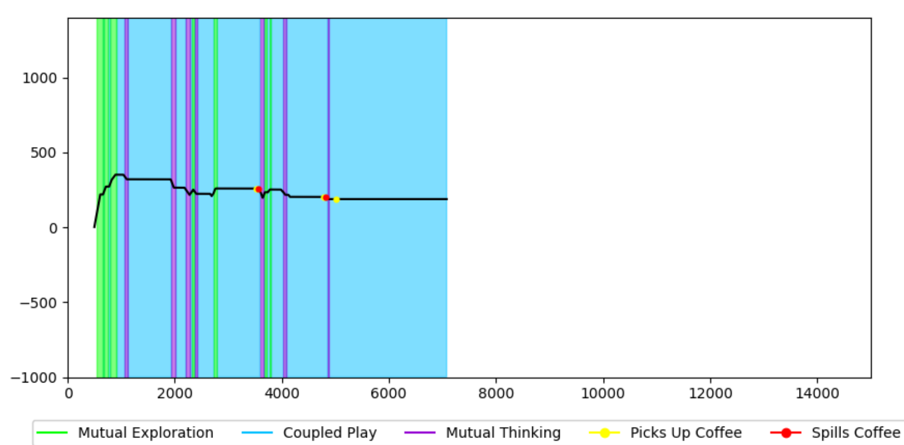

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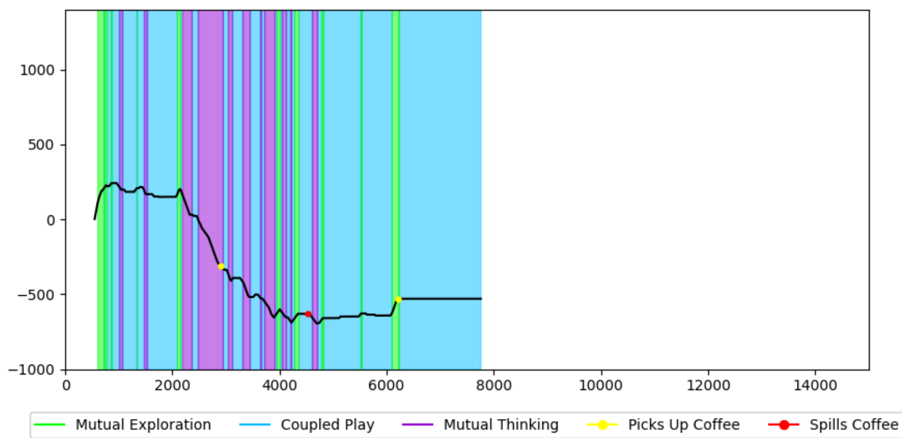

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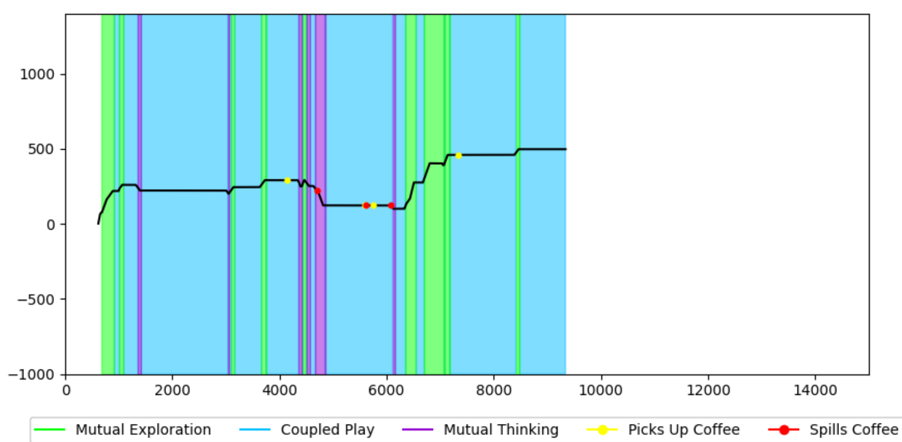

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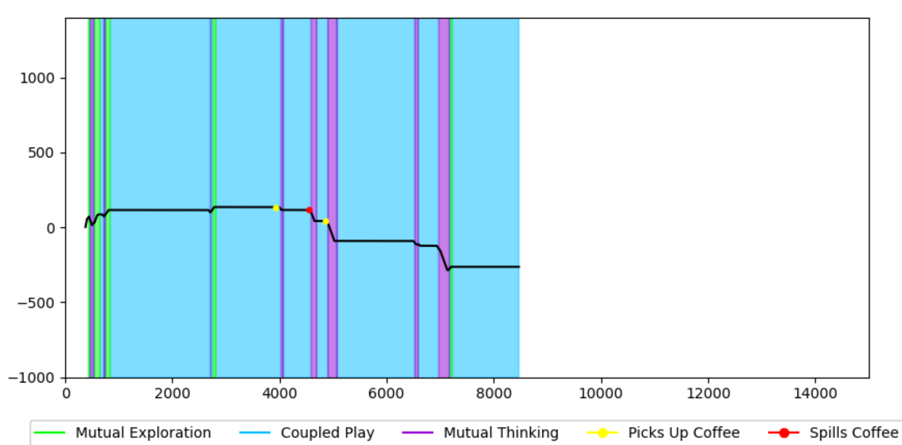

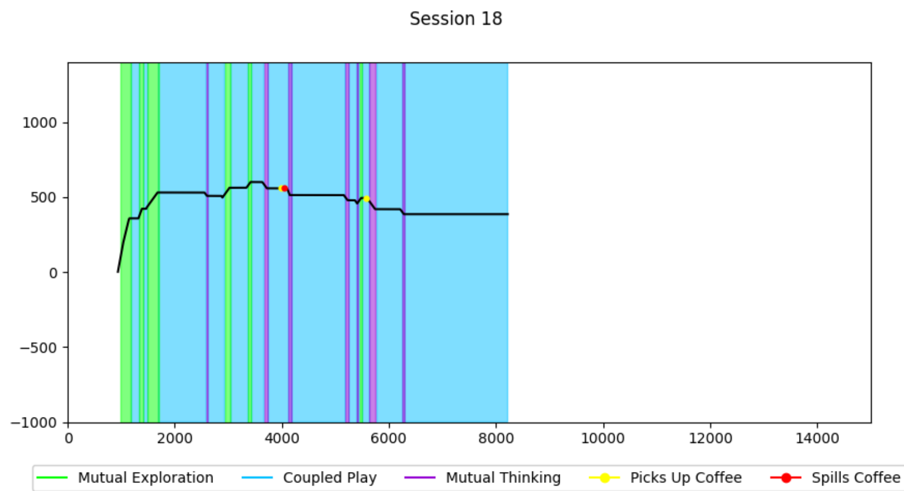
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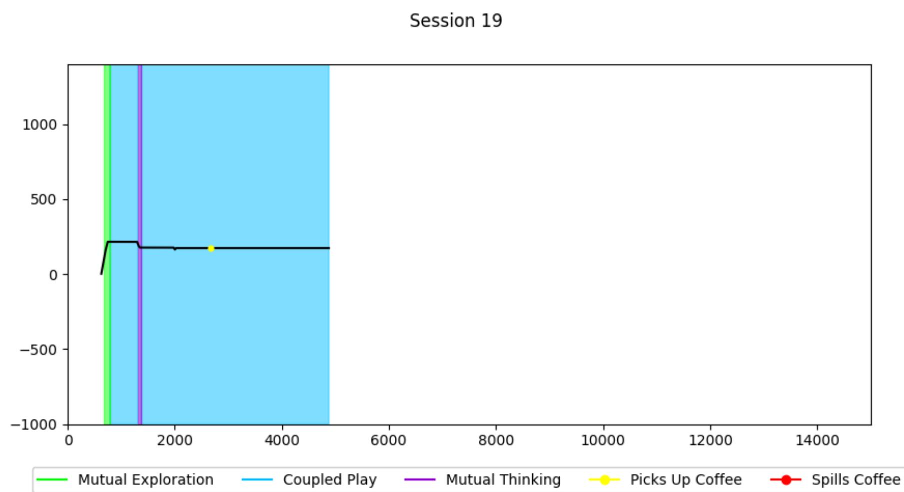
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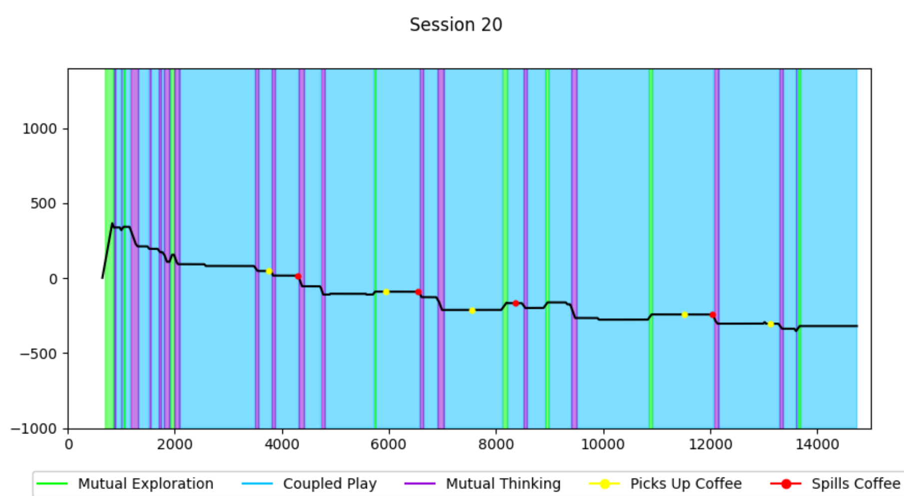
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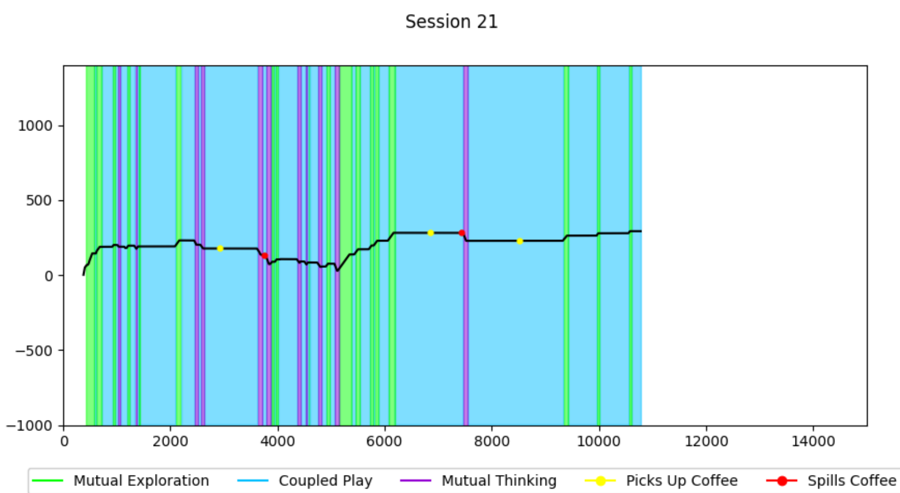

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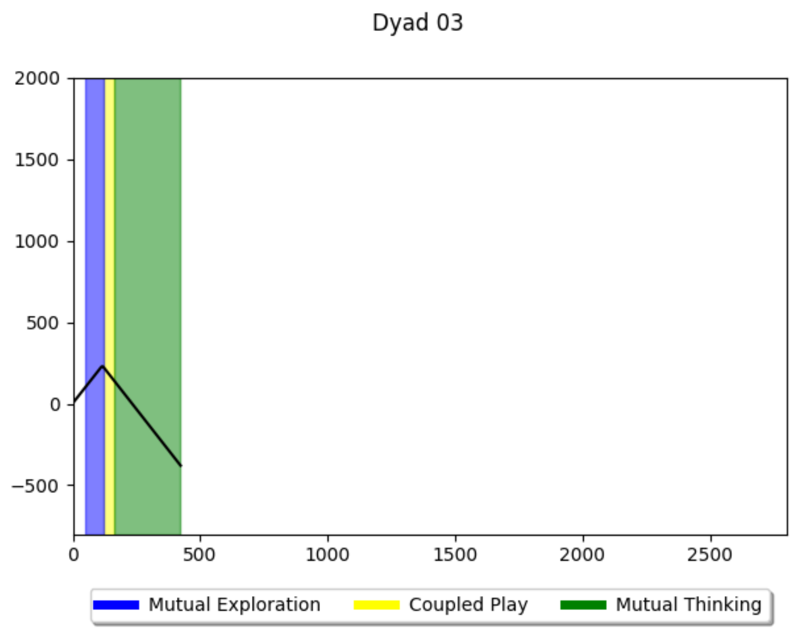
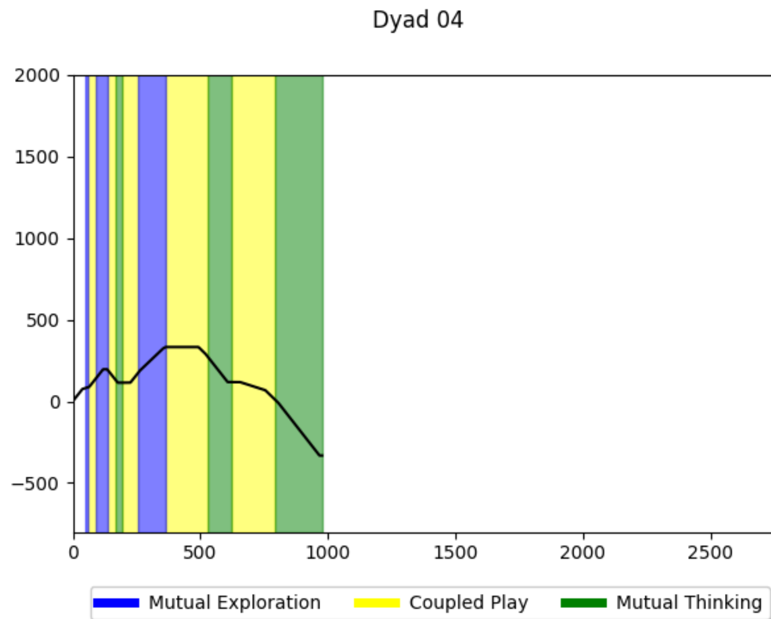
APPENDIX F

***SOUND HAPPENING* CREATIVE TRAJECTORY CURVES**

Frame numbers appear on the horizontal axis, and the cumulative integral sum for both players is plotted on the vertical axis.



*Curve unable to be shaded due to a consistent downward slope in the creative trajectory curve for nearly the full duration of the session, which primarily included the two participants throwing beach balls at one another. This curve has been classified as a state of mutual thinking due to the downward slope of the creative trajectory, although it should be noted that the "mutual thinking" in this case refers to a complete perceptual disconnection and/or disengagement from the interaction.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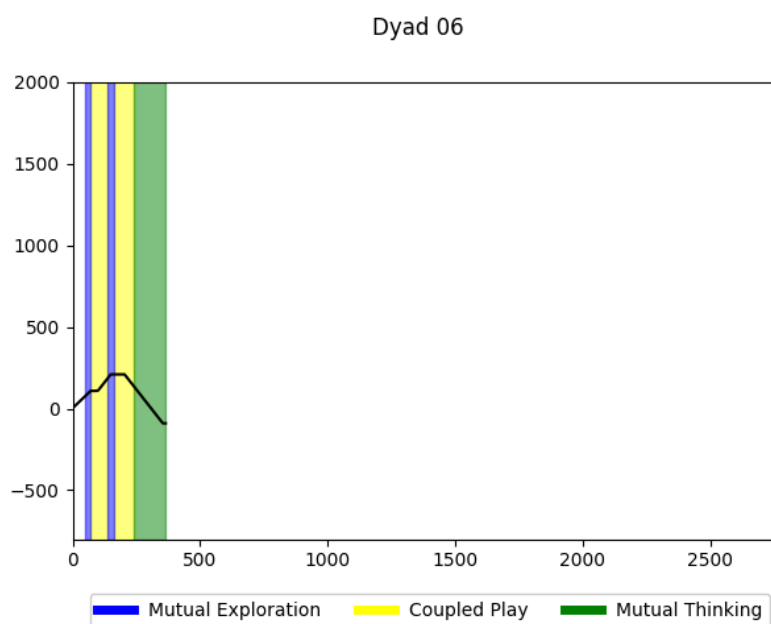
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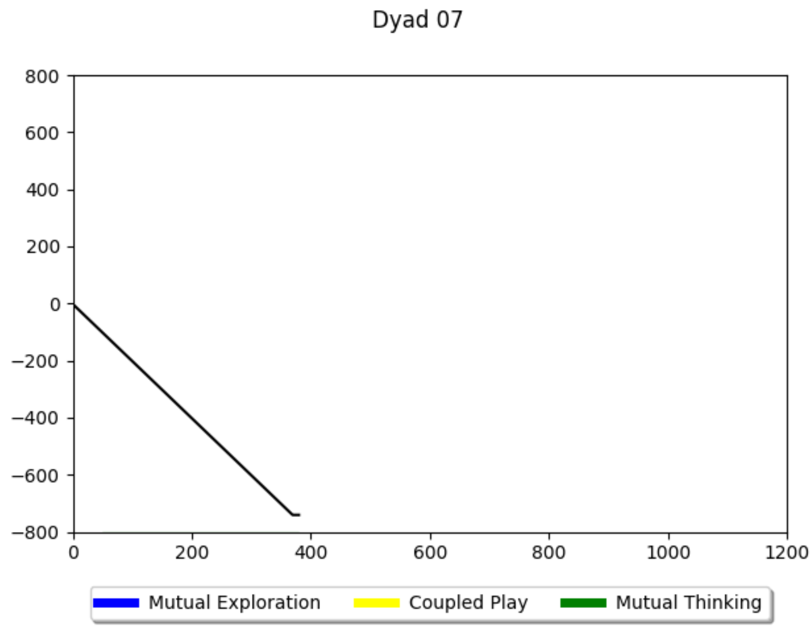
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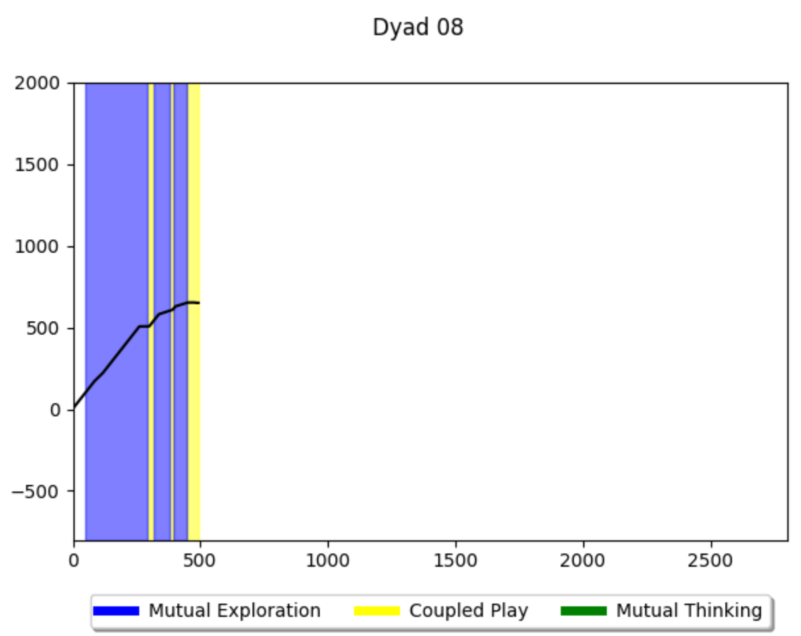
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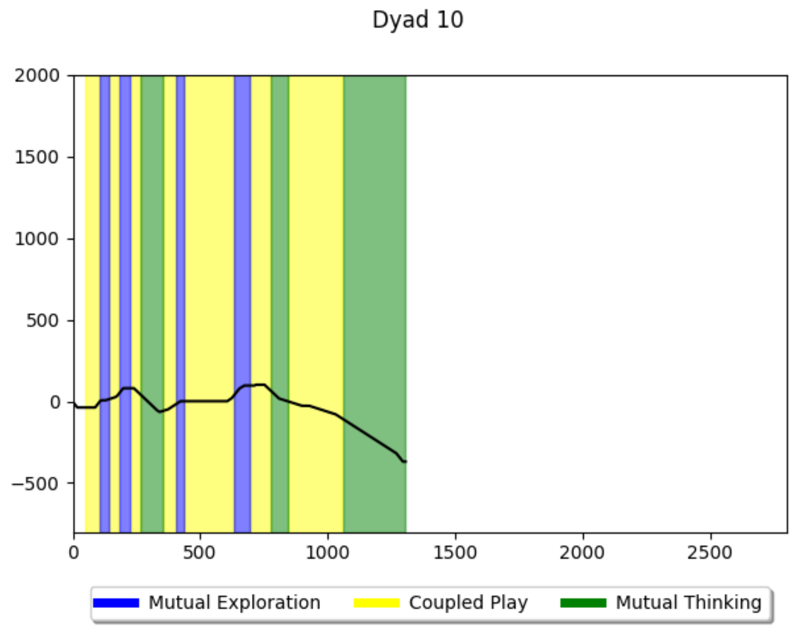
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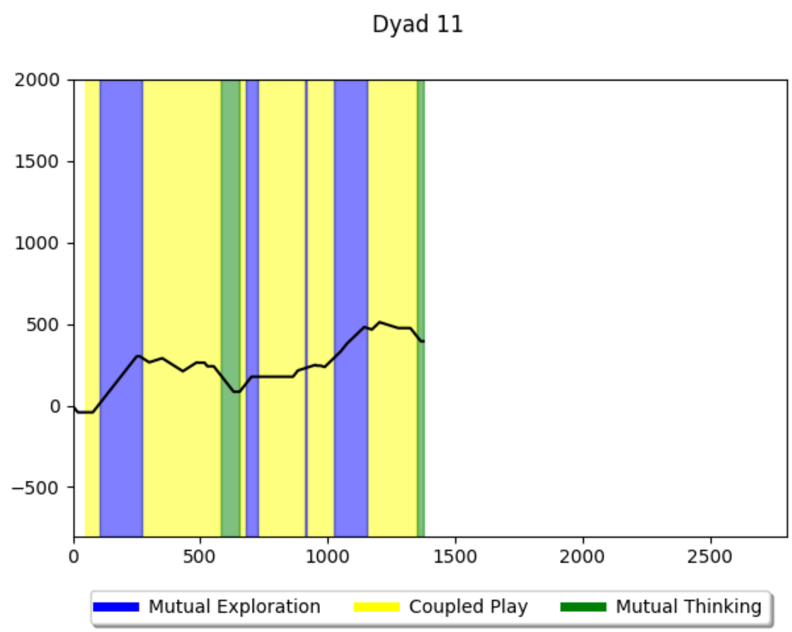
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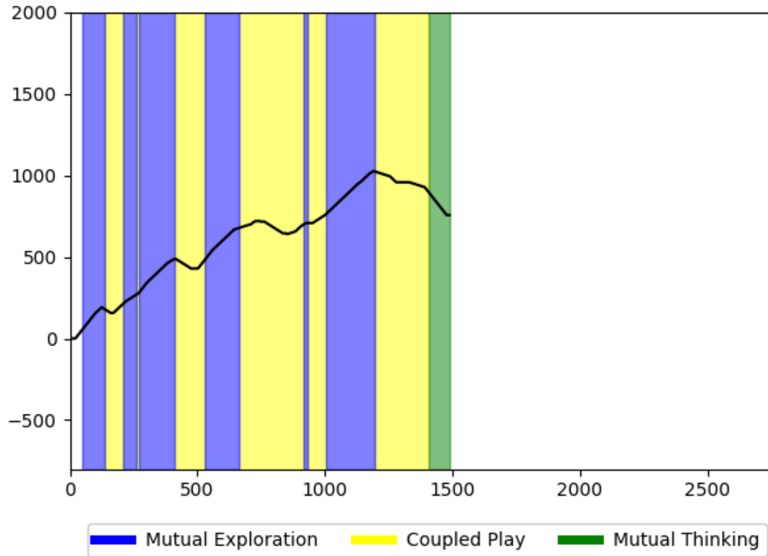
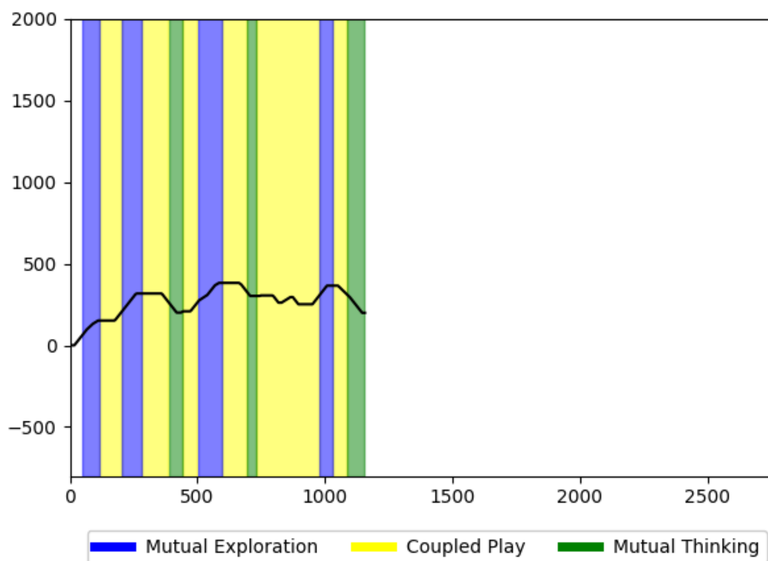
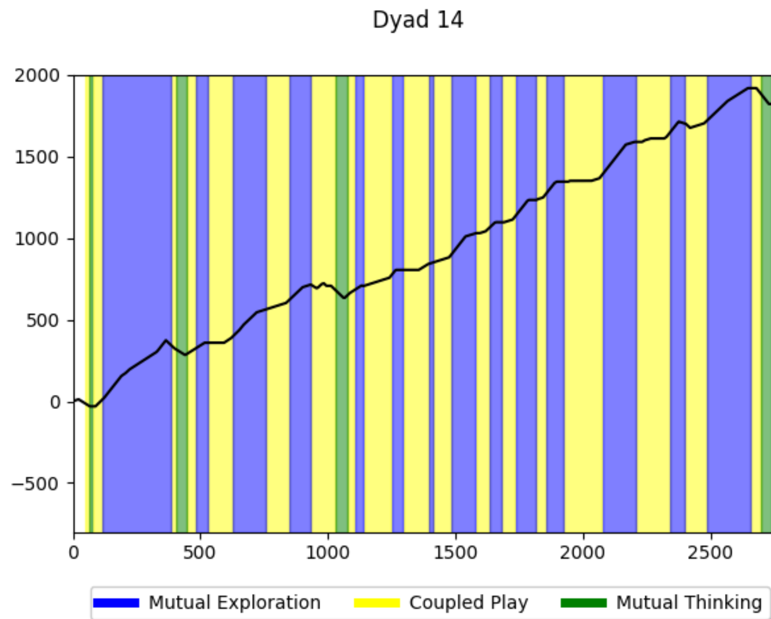
Mutual Thinking

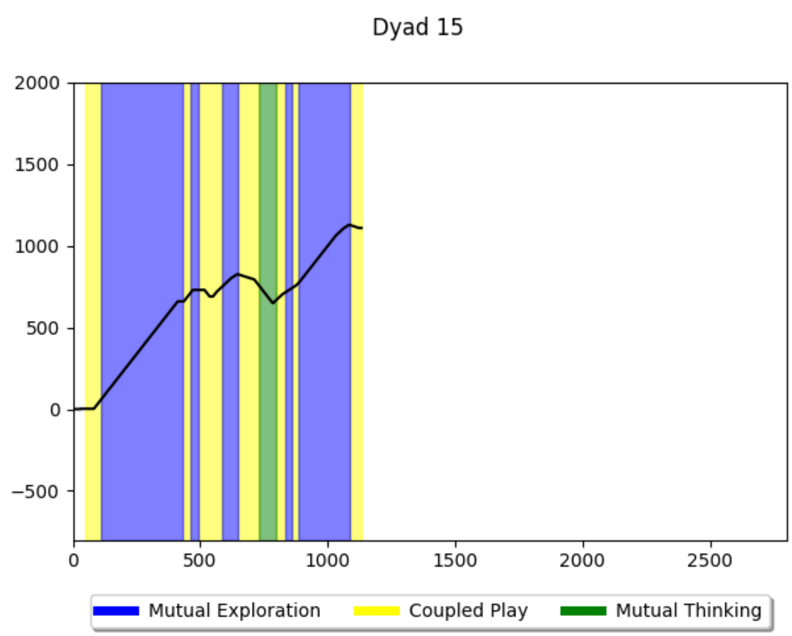
Dyad 12

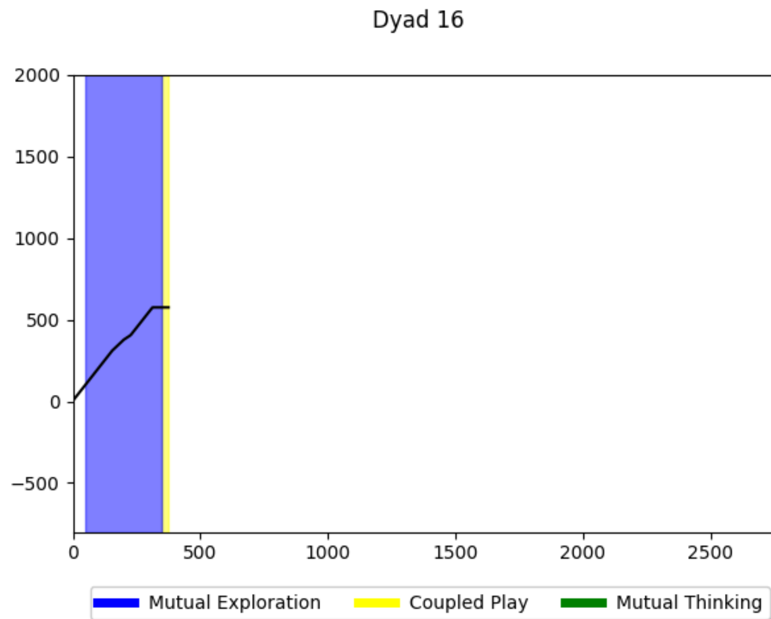


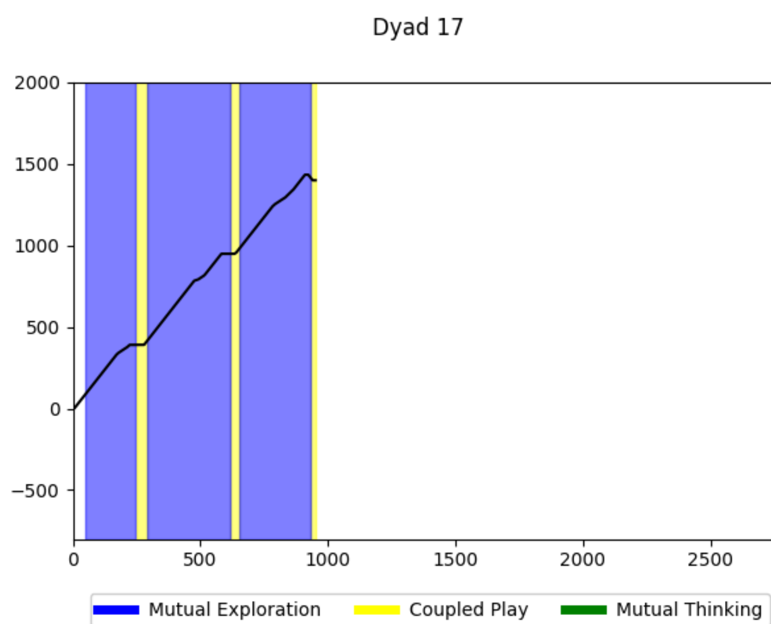
Dyad 13

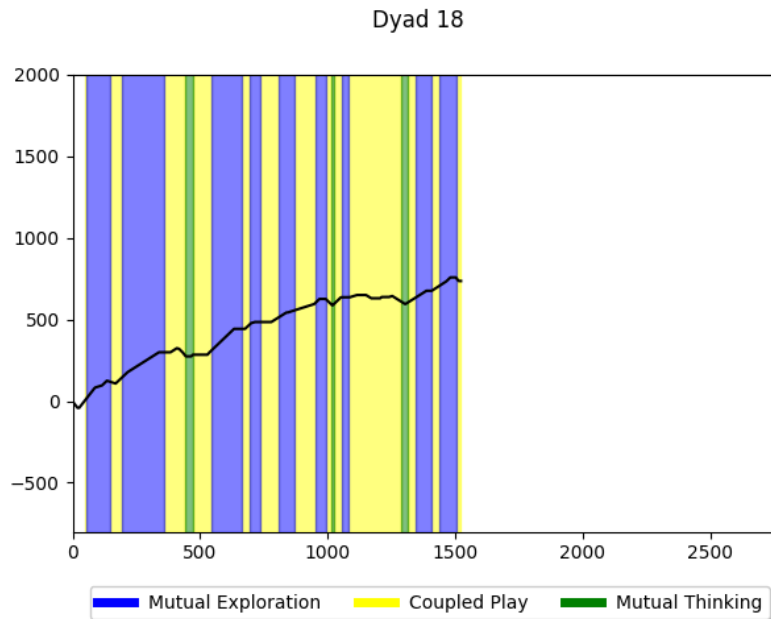


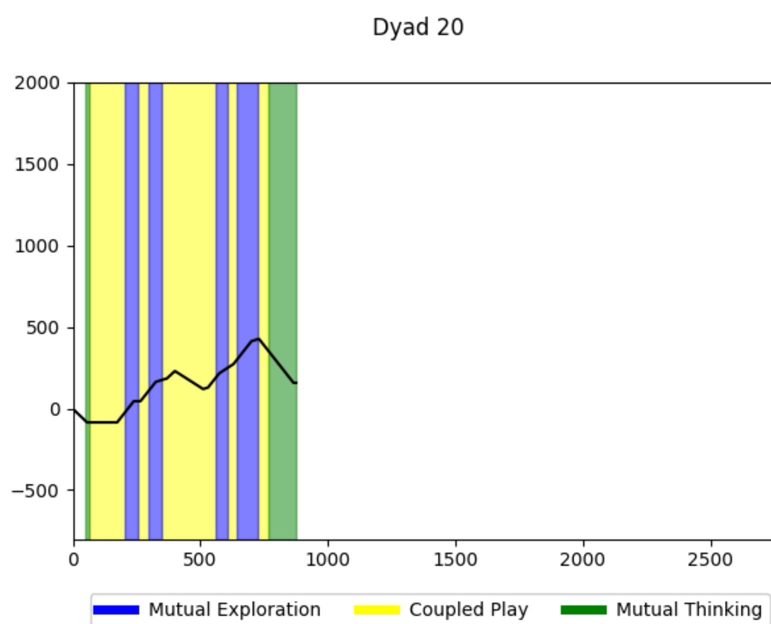

Dyad 14
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

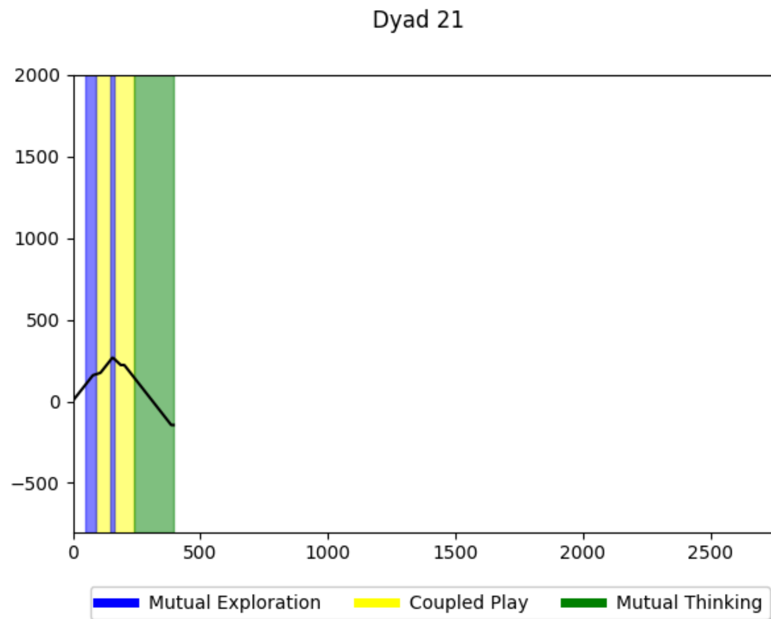

Dyad 15
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

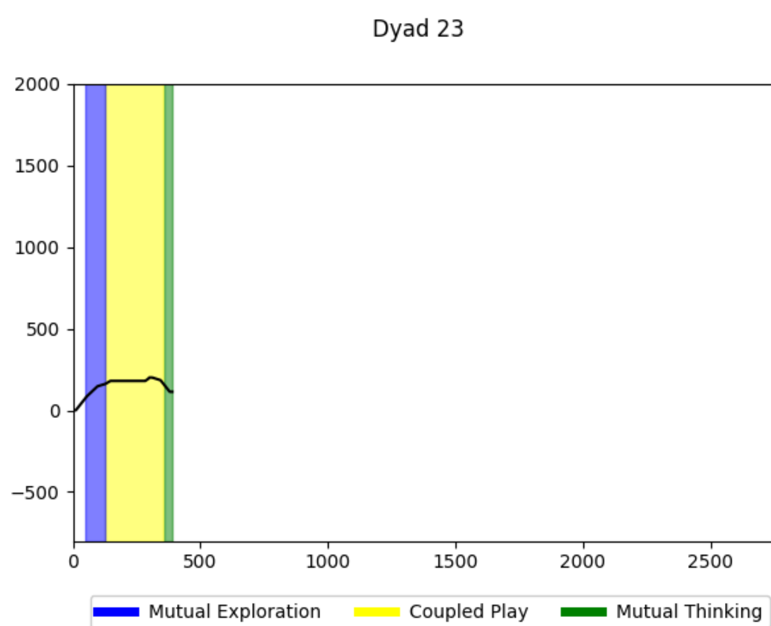

Dyad 16
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

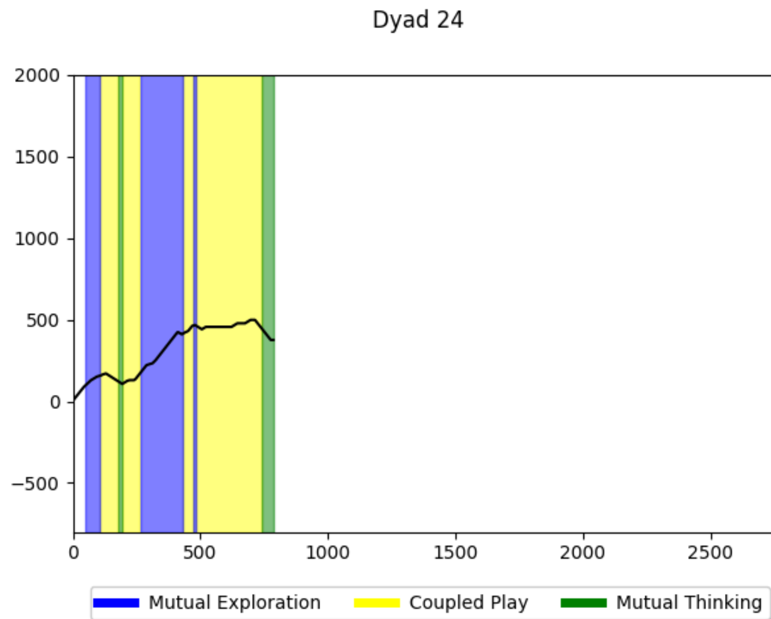

Dyad 17
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

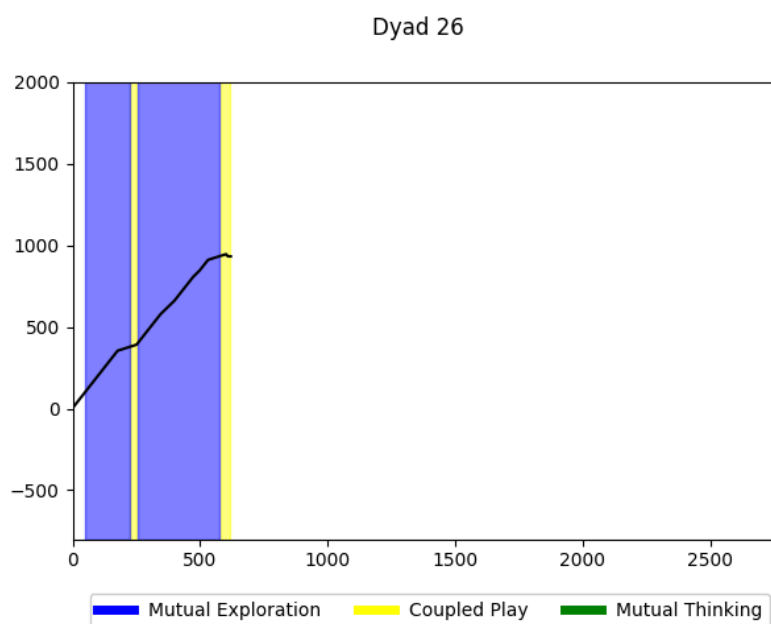

Dyad 18
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

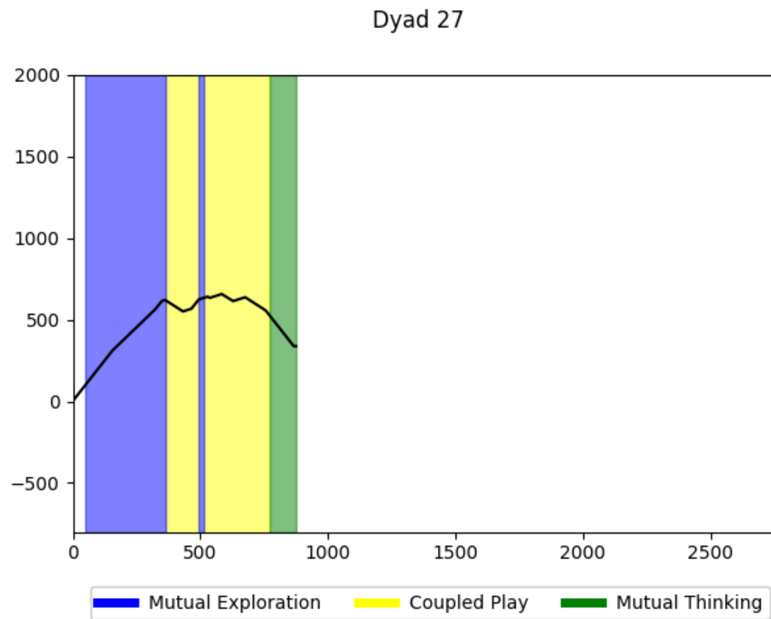

Dyad 20
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

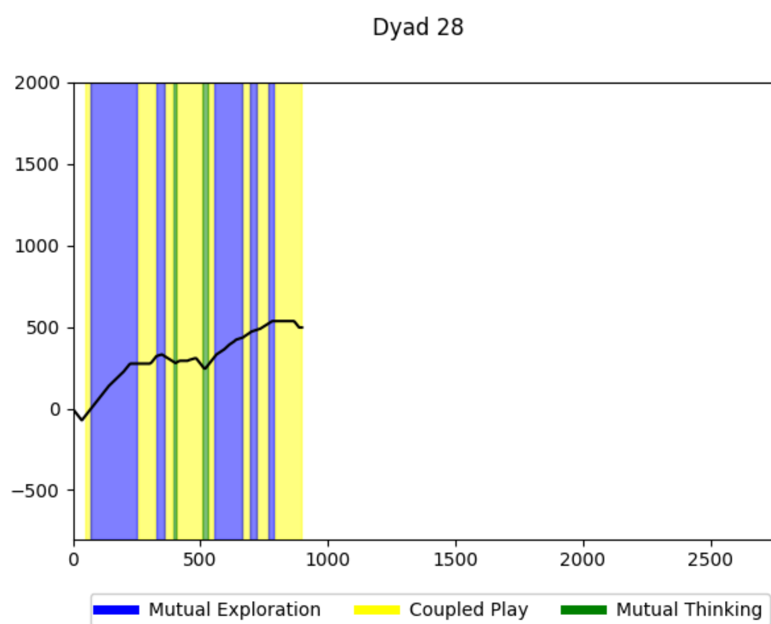

Dyad 21
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

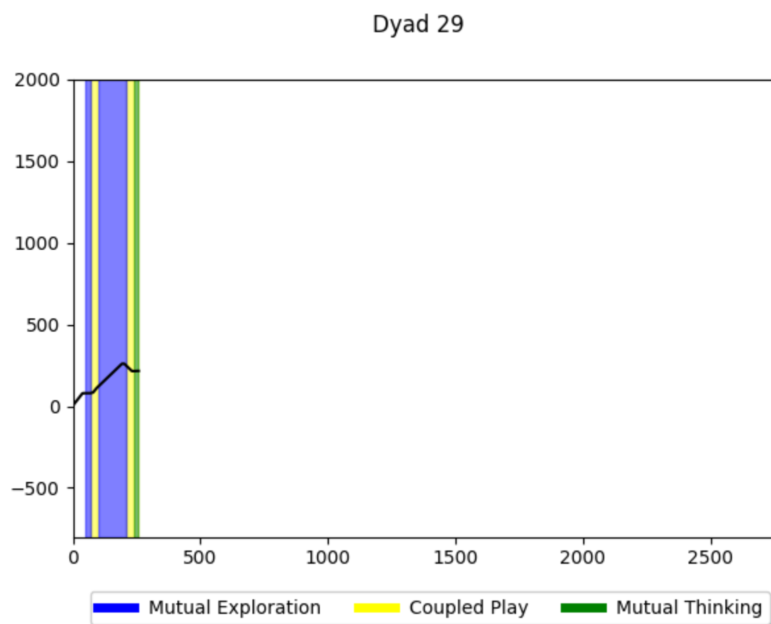

Dyad 23
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

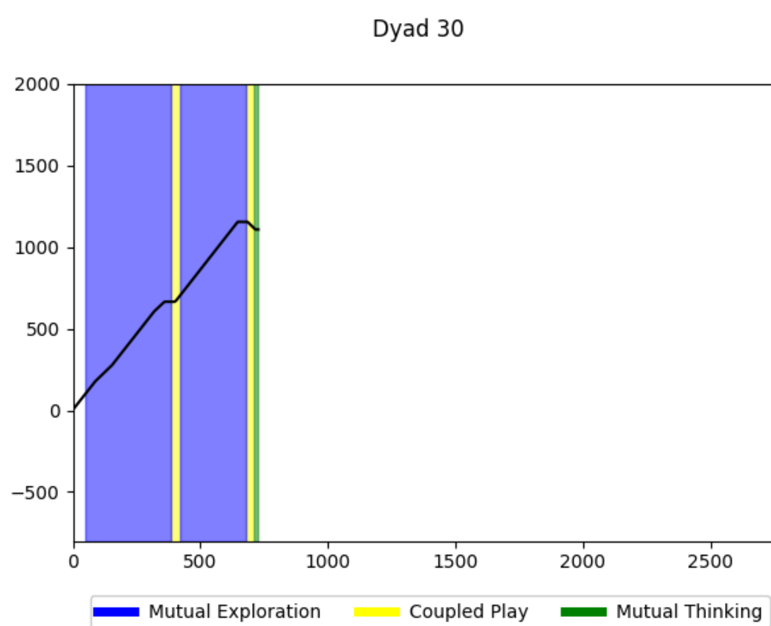

Dyad 24
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

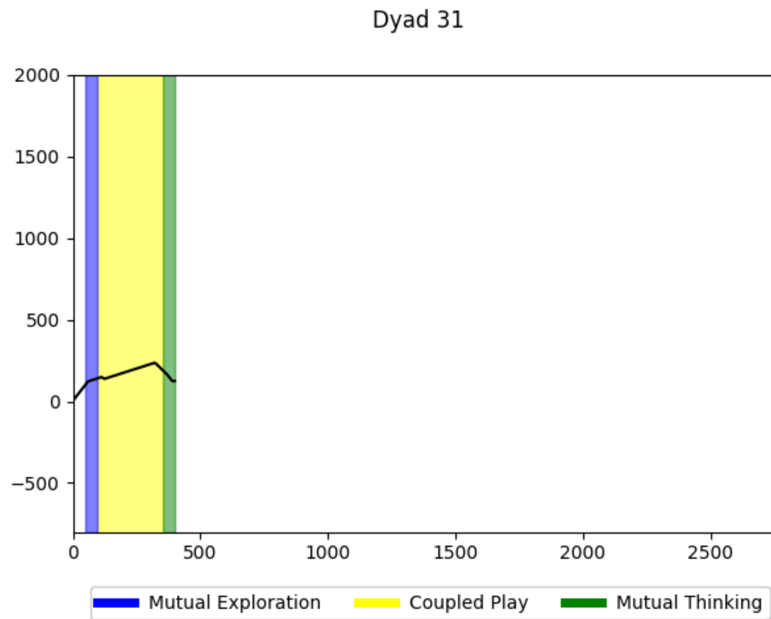

Dyad 26
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

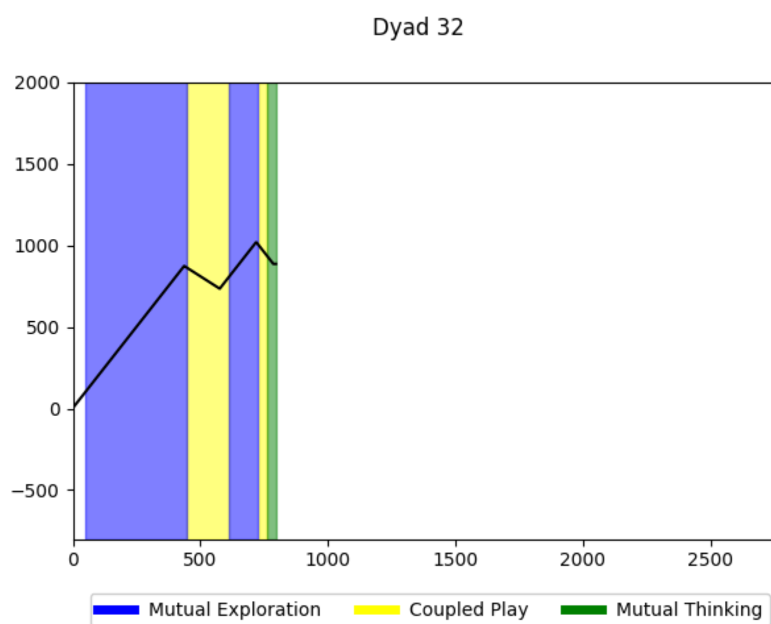

Dyad 27
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

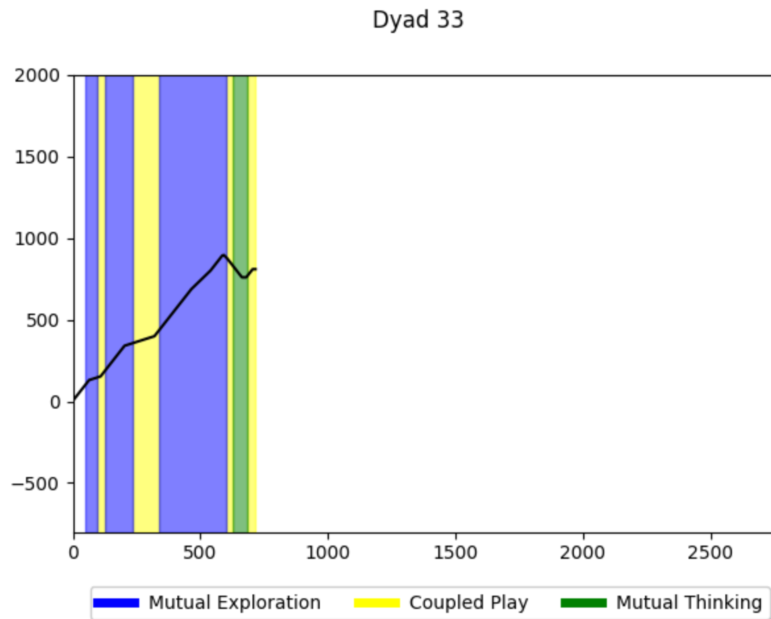

Dyad 28
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

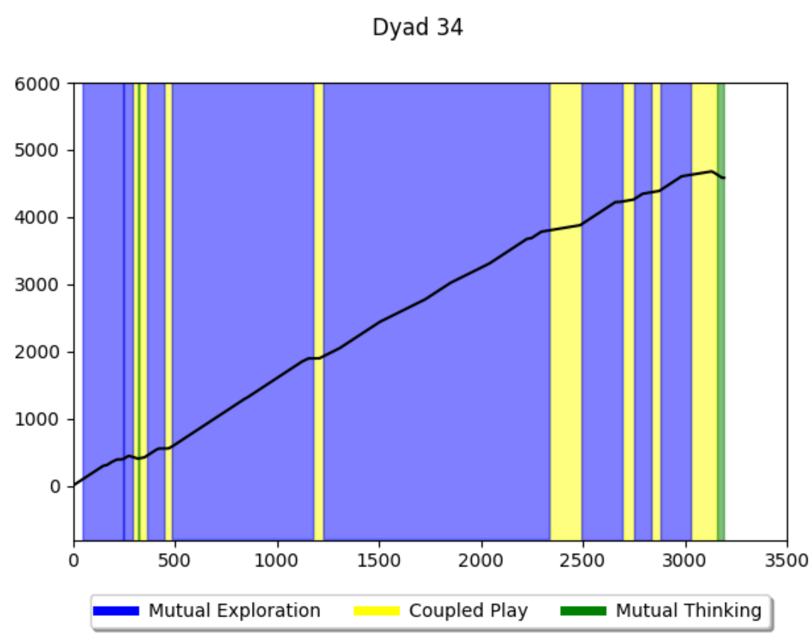

Dyad 29
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

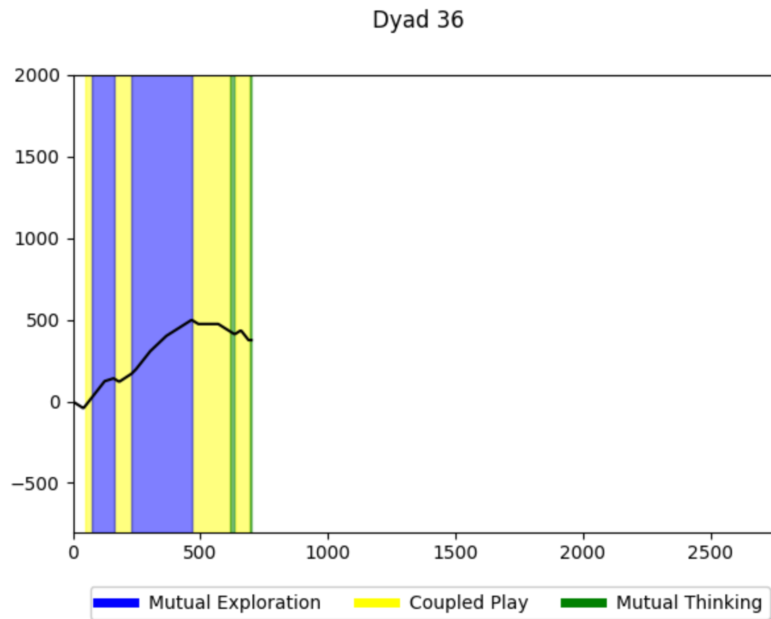

Dyad 30
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

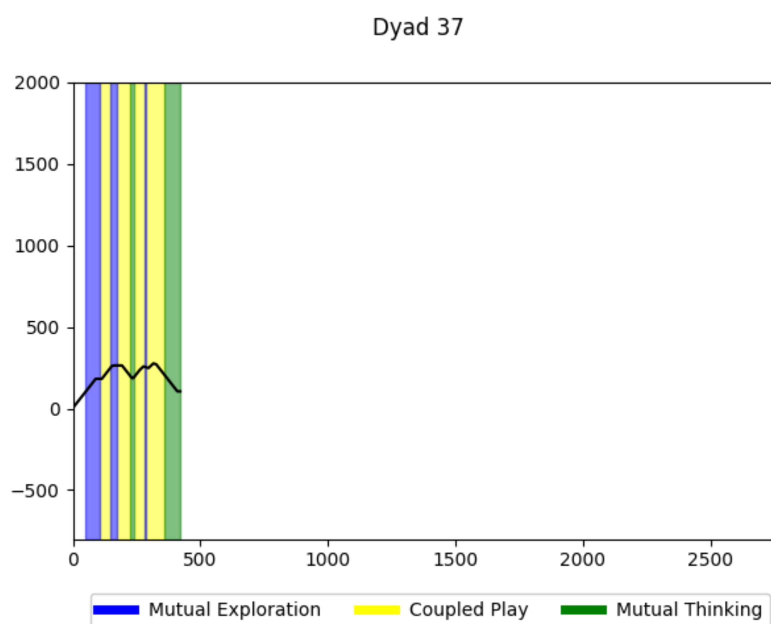

Dyad 31
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

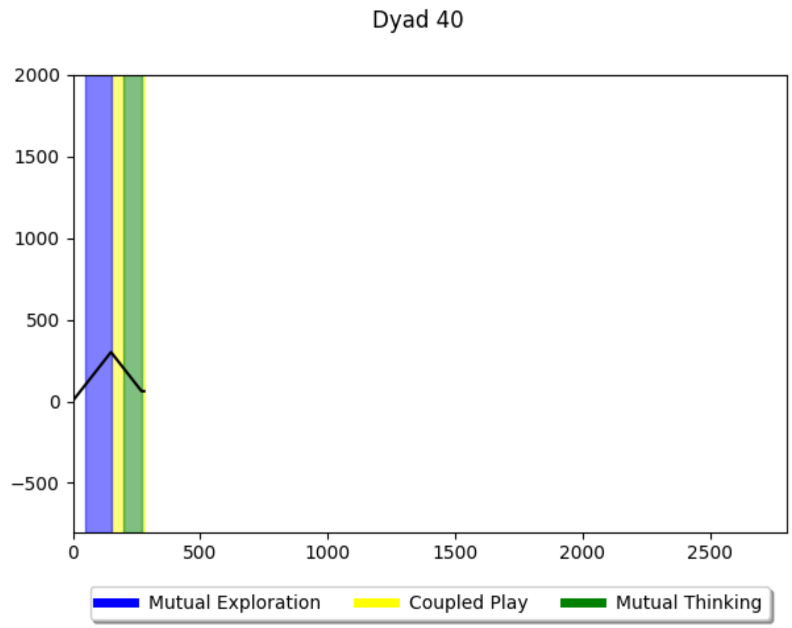

Dyad 32
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

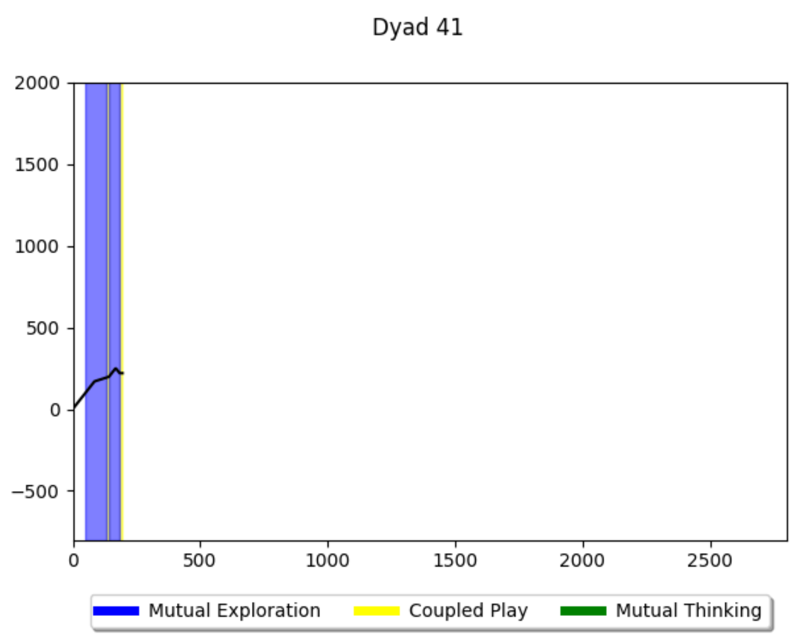

Dyad 33
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

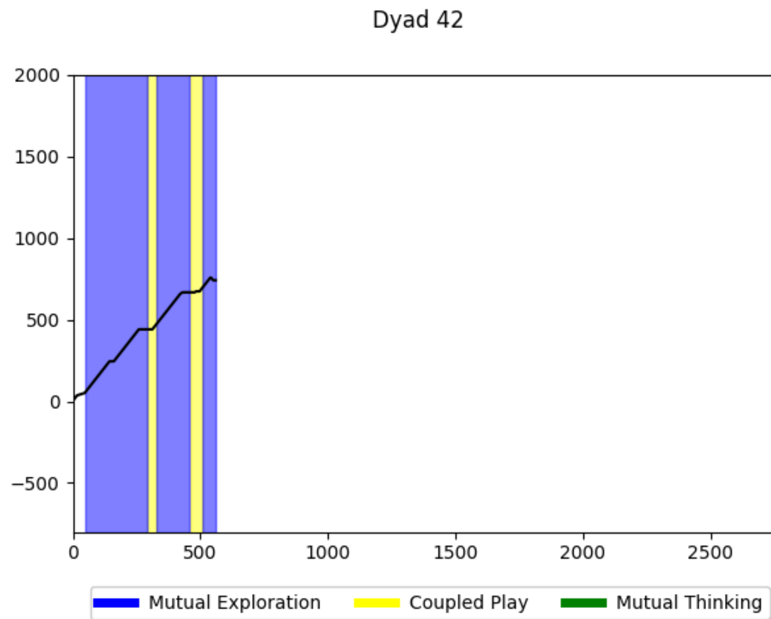

Dyad 34
6000
5000
4000
3000
2000
1000
0
0
500
1000
1500
2000
2500
3000
3500
Mutual Exploration
Coupled Play
Mutual Thinking

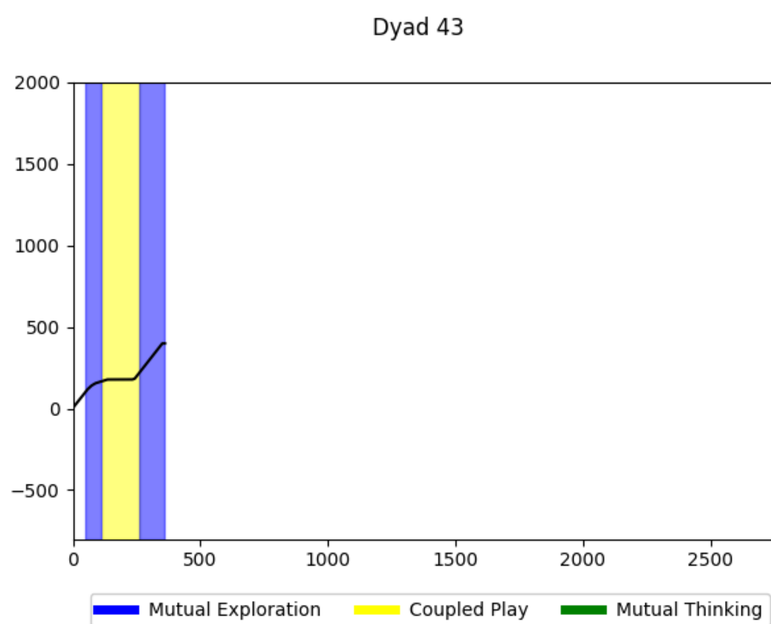

Dyad 36
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking


Dyad 37
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

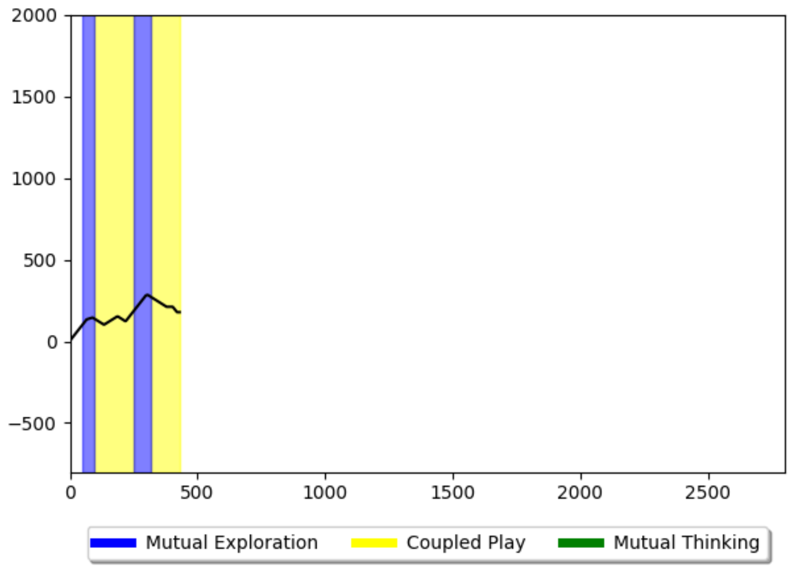

Dyad 40
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking


Dyad 41
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking


Dyad 42
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking


Dyad 43
2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

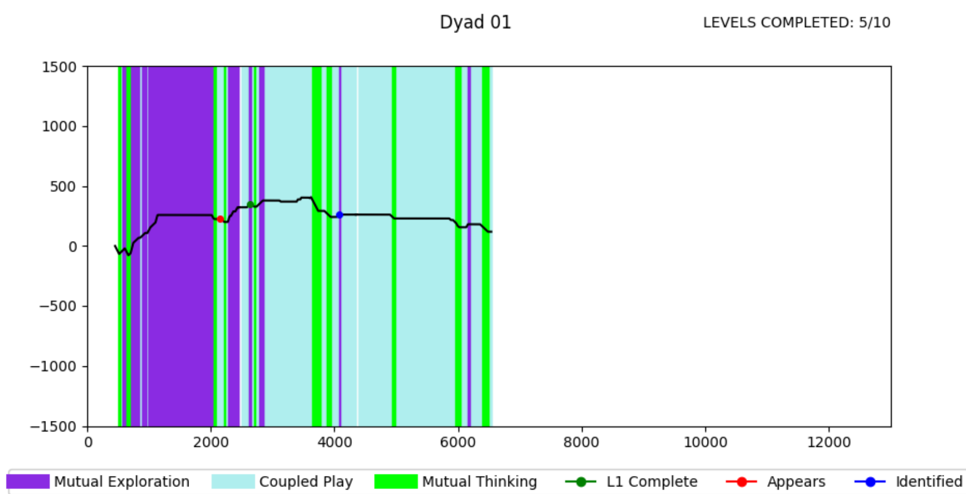
Dyad 44

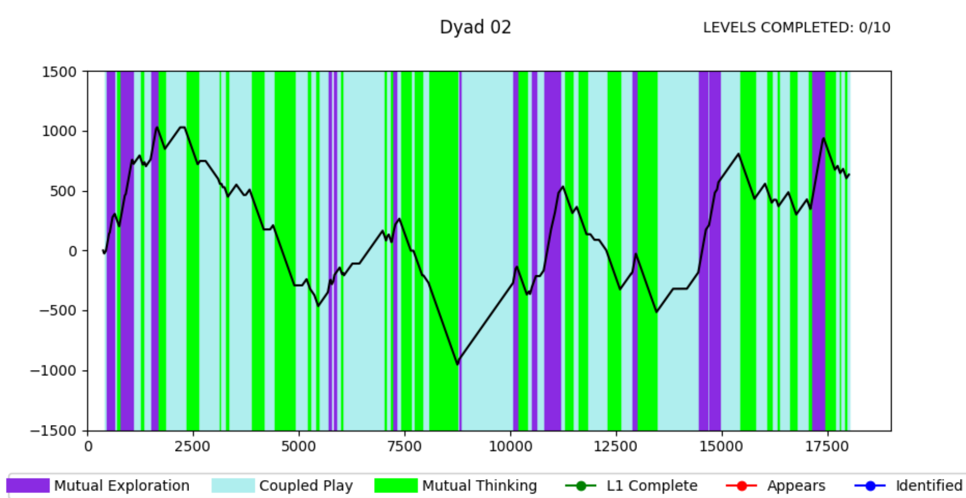

2000
1500
1000
500
0
−500
0
500
1000
1500
2000
2500
Mutual Exploration
Coupled Play
Mutual Thinking

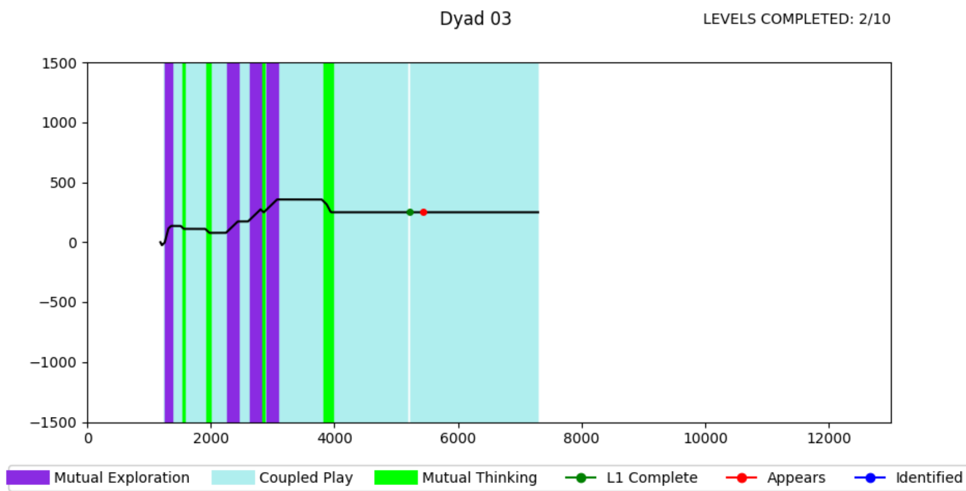
APPENDIX G

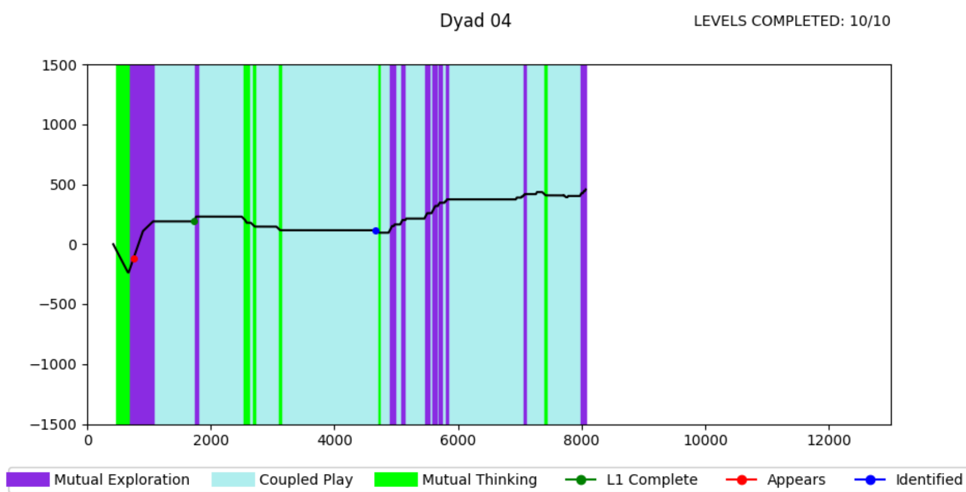
TRIP CREATIVE TRAJECTORY CURVES

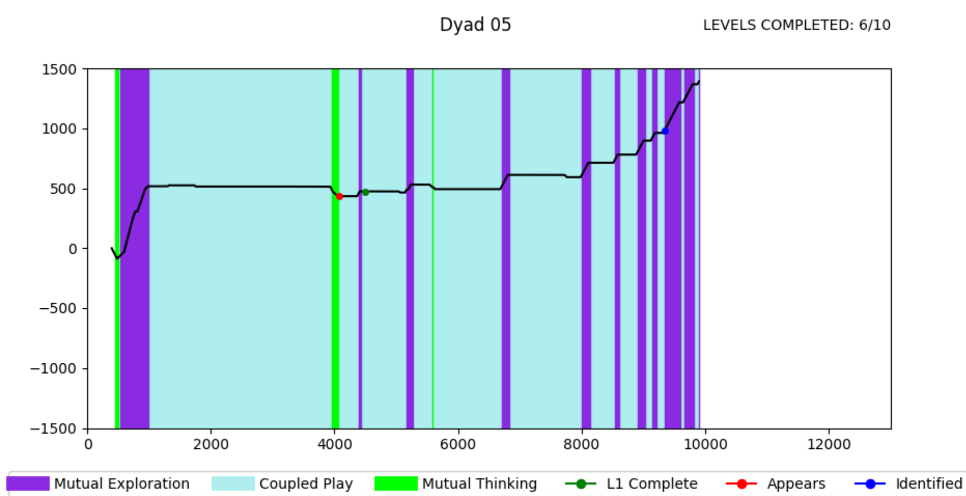
Frame numbers appear on the horizontal axis, and the cumulative integral sum for both players is plotted on the vertical axis. The first appearance of a control panel object is plotted in red. The first successful control panel interaction is plotted in blue. Completion of the game's first level is plotted in green. Time periods in which a facilitator restarted the game due to failure of the first level were excluded from creative sense-making analysis.

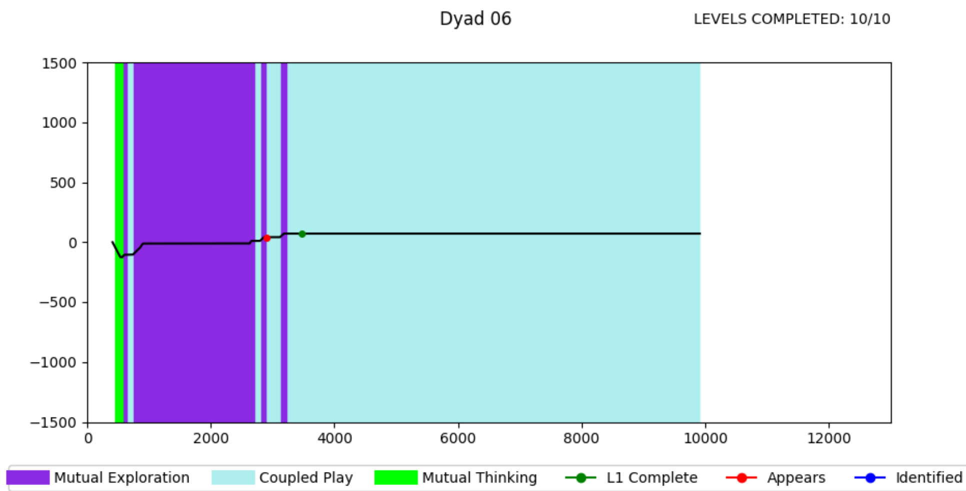


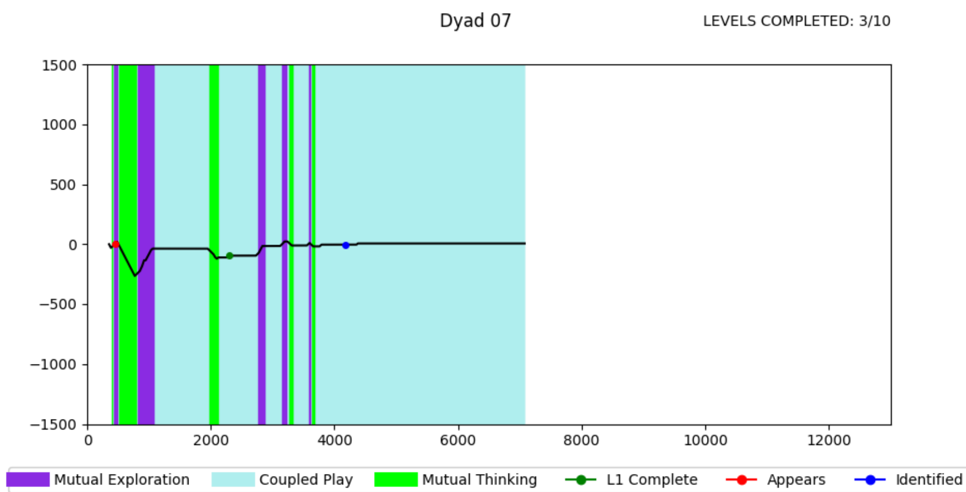


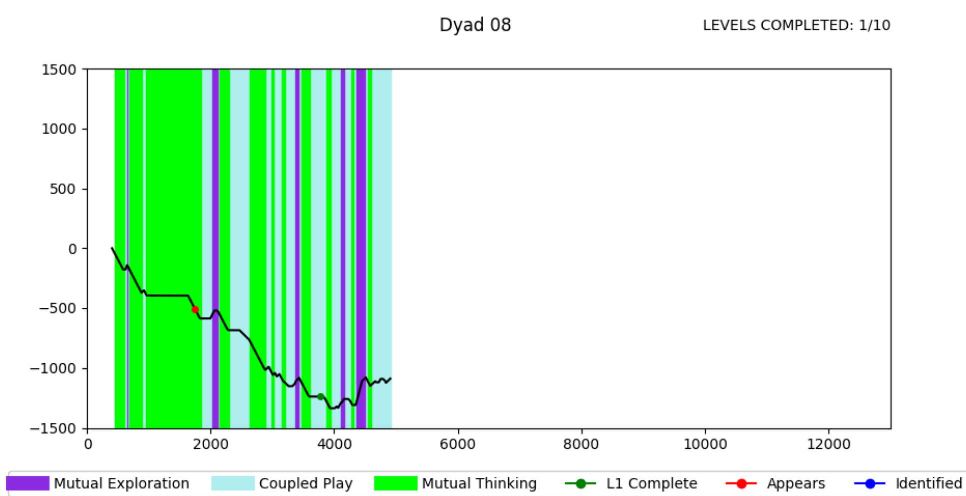

Dyad 03
LEVELS COMPLETED: 2/10
1500
1000
500
0
−500
−1000
−1500
0
2000
4000
6000
8000
10000
12000
Mutual Exploration
Coupled Play
Mutual Thinking
L1 Complete
Appears
Identified

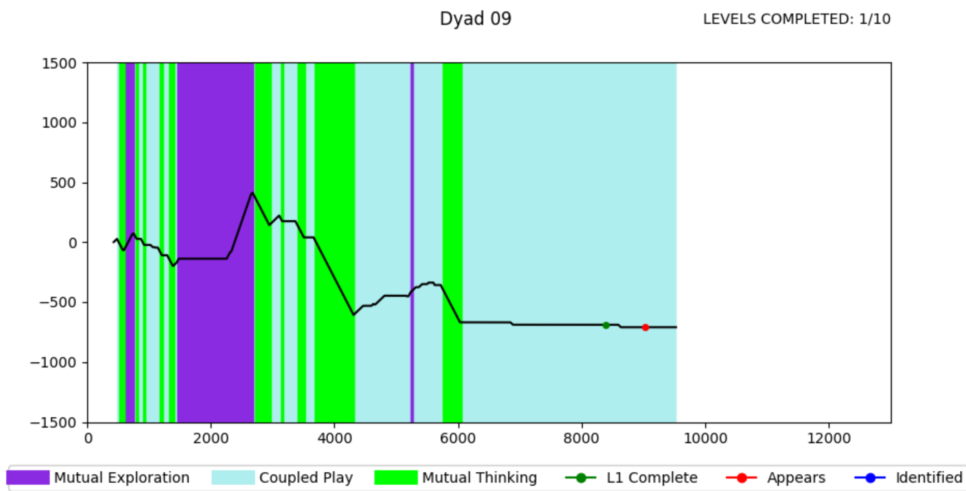

Dyad 04
LEVELS COMPLETED: 10/10
1500
1000
500
0
−500
−1000
−1500
0
2000
4000
6000
8000
10000
12000
Mutual Exploration
Coupled Play
Mutual Thinking
L1 Complete
Appears
Identified

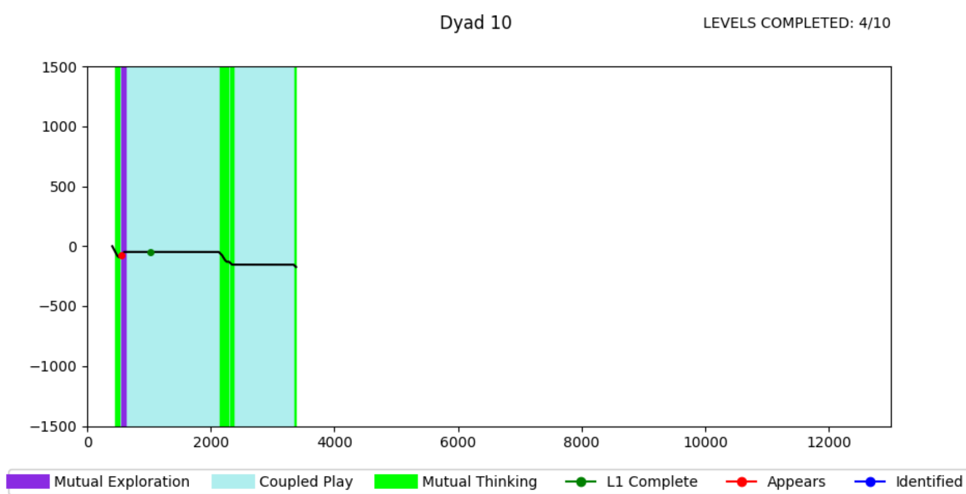

Dyad 05
LEVELS COMPLETED: 6/10
1500
1000
500
0
−500
−1000
−1500
0
2000
4000
6000
8000
10000
12000
Mutual Exploration
Coupled Play
Mutual Thinking
L1 Complete
Appears
Identified

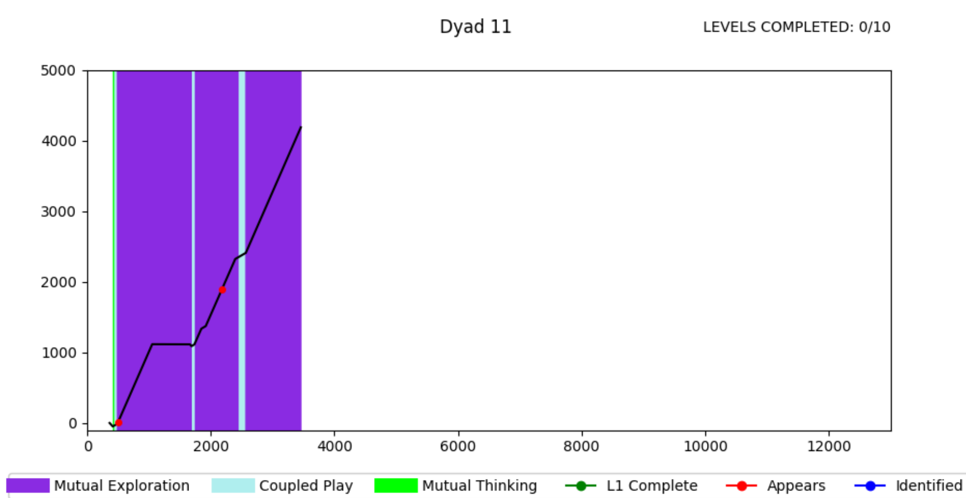

Dyad 06
LEVELS COMPLETED: 10/10
1500
1000
500
0
−500
−1000
−1500
0
2000
4000
6000
8000
10000
12000
Mutual Exploration
Coupled Play
Mutual Thinking
L1 Complete
Appears
Identified

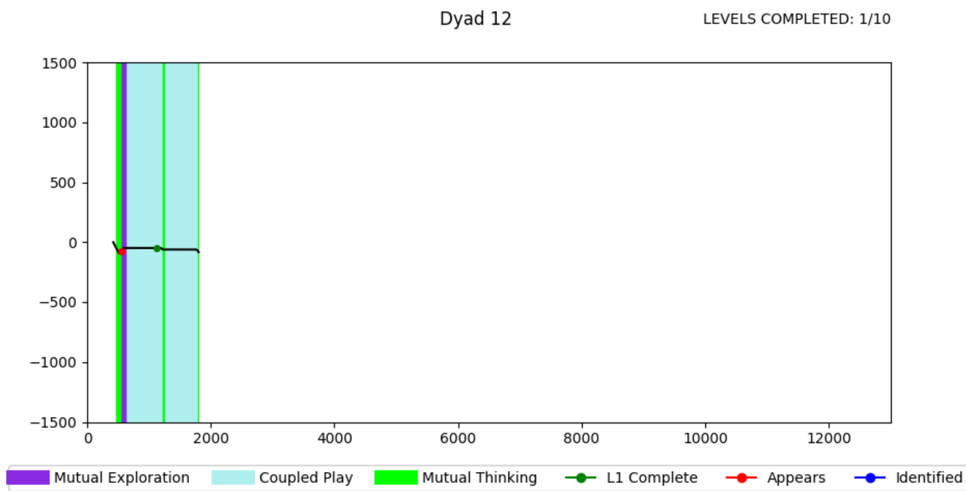

Dyad 07
LEVELS COMPLETED: 3/10
1500
1000
500
0
−500
−1000
−1500
0
2000
4000
6000
8000
10000
12000
Mutual Exploration
Coupled Play
Mutual Thinking
L1 Complete
Appears
Identified

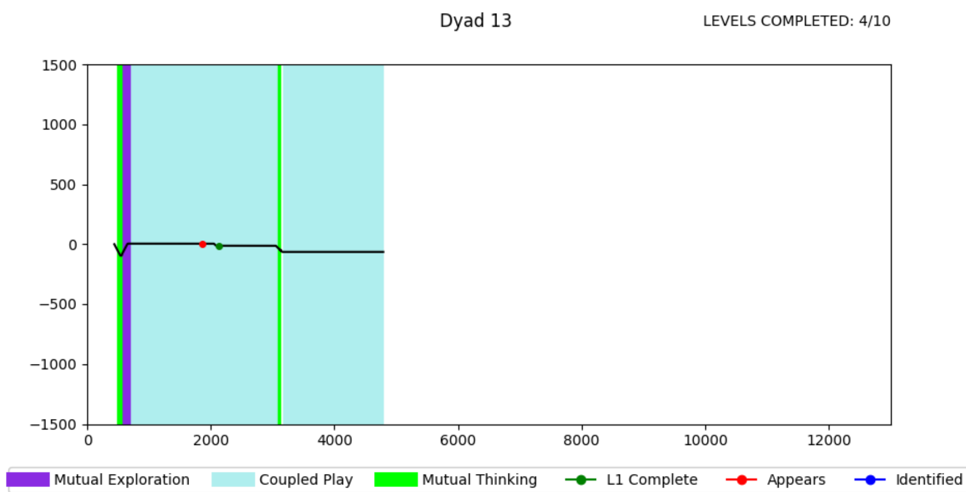

Dyad 08
LEVELS COMPLETED: 1/10
1500
1000
500
0
−500
−1000
−1500
0
2000
4000
6000
8000
10000
12000
Mutual Exploration
Coupled Play
Mutual Thinking
L1 Complete
Appears
Identified

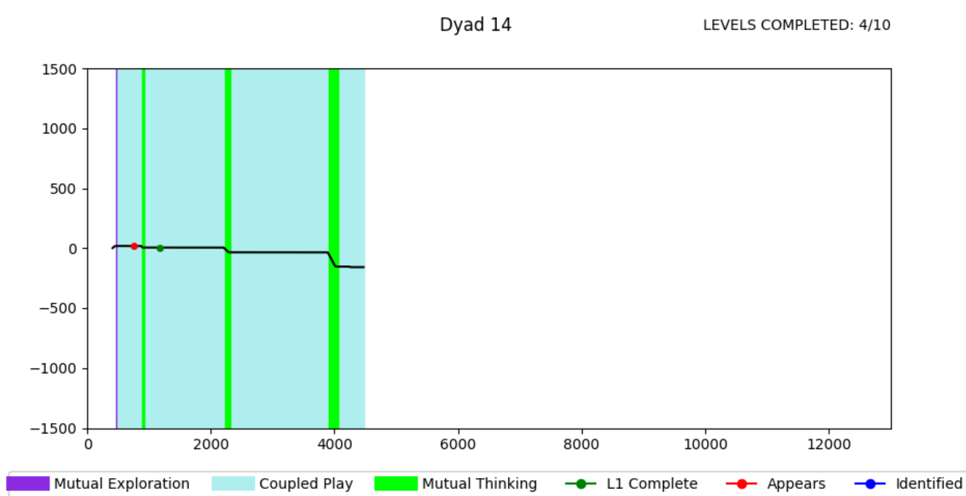

Dyad 09
LEVELS COMPLETED: 1/10
1500
1000
500
0
−500
−1000
−1500
0
2000
4000
6000
8000
10000
12000
Mutual Exploration
Coupled Play
Mutual Thinking
L1 Complete
Appears
Identified

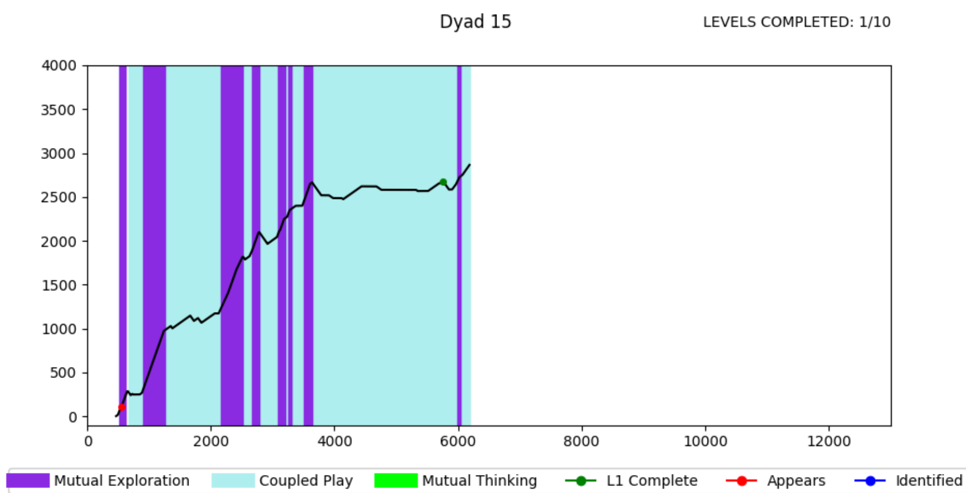

Dyad 10
LEVELS COMPLETED: 4/10
1500
1000
500
0
−500
−1000
−1500
0
2000
4000
6000
8000
10000
12000
Mutual Exploration
Coupled Play
Mutual Thinking
L1 Complete
Appears
Identified


Dyad 11
LEVELS COMPLETED: 0/10
5000
4000
3000
2000
1000
0
0
2000
4000
6000
8000
10000
12000
Mutual Exploration
Coupled Play
Mutual Thinking
L1 Complete
Appears
Identified


Dyad 12
LEVELS COMPLETED: 1/10
1500
1000
500
0
−500
−1000
−1500
0
2000
4000
6000
8000
10000
12000
Mutual Exploration
Coupled Play
Mutual Thinking
L1 Complete
Appears
Identified


Dyad 13
LEVELS COMPLETED: 4/10
1500
1000
500
0
−500
−1000
−1500
0
2000
4000
6000
8000
10000
12000
Mutual Exploration
Coupled Play
Mutual Thinking
L1 Complete
Appears
Identified

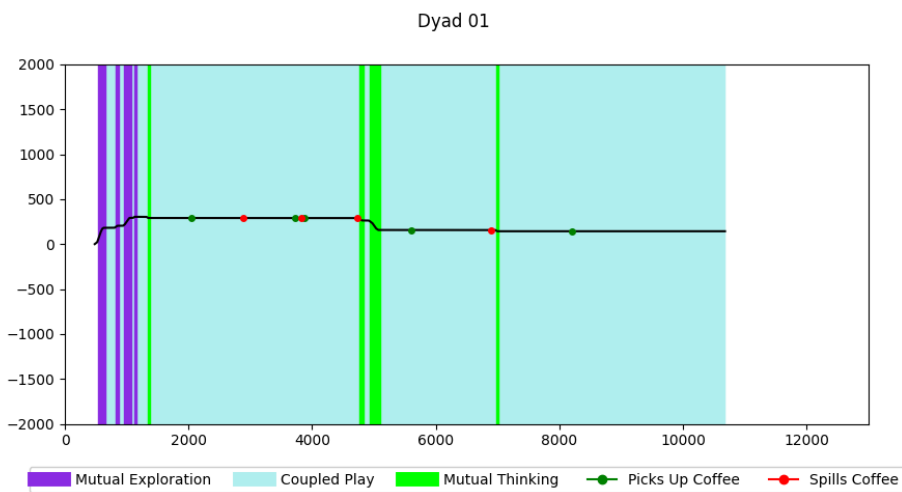

Dyad 14
LEVELS COMPLETED: 4/10
1500
1000
500
0
−500
−1000
−1500
0
2000
4000
6000
8000
10000
12000
Mutual Exploration
Coupled Play
Mutual Thinking
L1 Complete
Appears
Identified

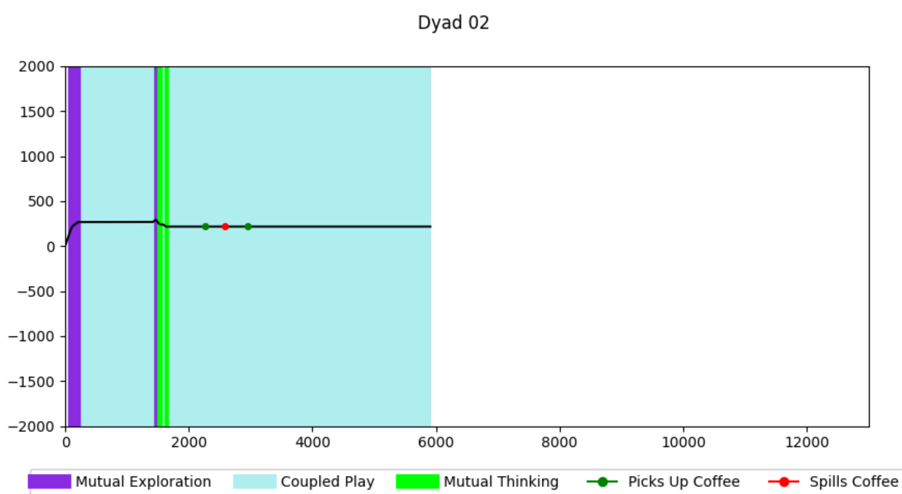

Dyad 15
LEVELS COMPLETED: 1/10
4000
3500
3000
2500
2000
1500
1000
500
0
0
2000
4000
6000
8000
10000
12000
Mutual Exploration
Coupled Play
Mutual Thinking
L1 Complete
Appears
Identified

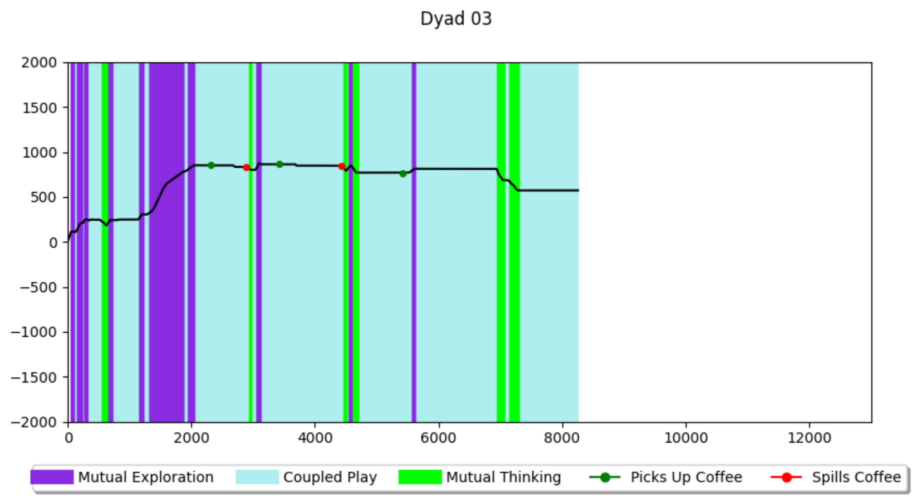
APPENDIX H

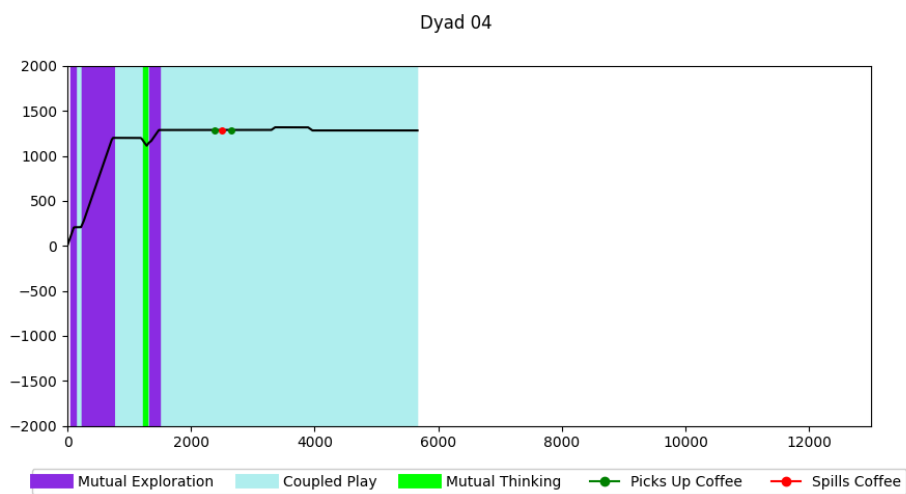
HABER DASHER GAMEPAD CONTROL CREATIVE TRAJECTORY CURVES

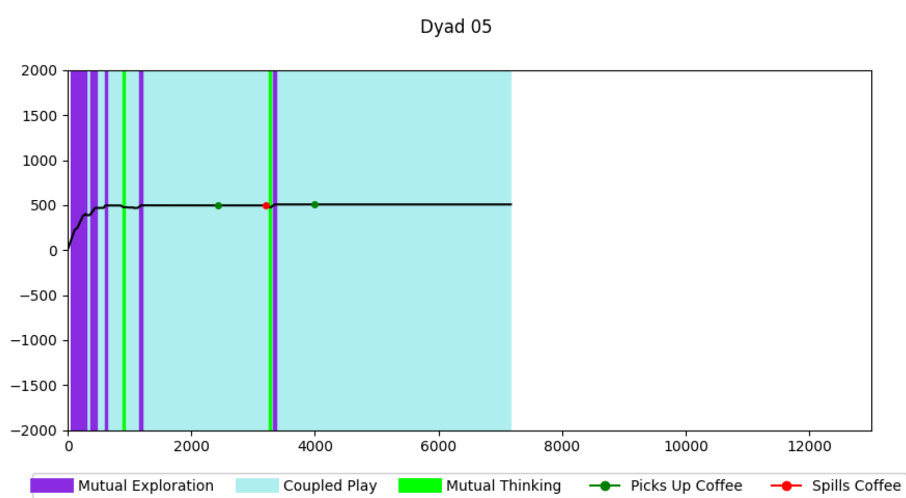
Frame numbers appear on the horizontal axis, and the cumulative integral sum for both players is plotted on the vertical axis. Events where players pick up a cup of coffee are plotted in green. Events where players spill their avatar's coffee are plotted in red.

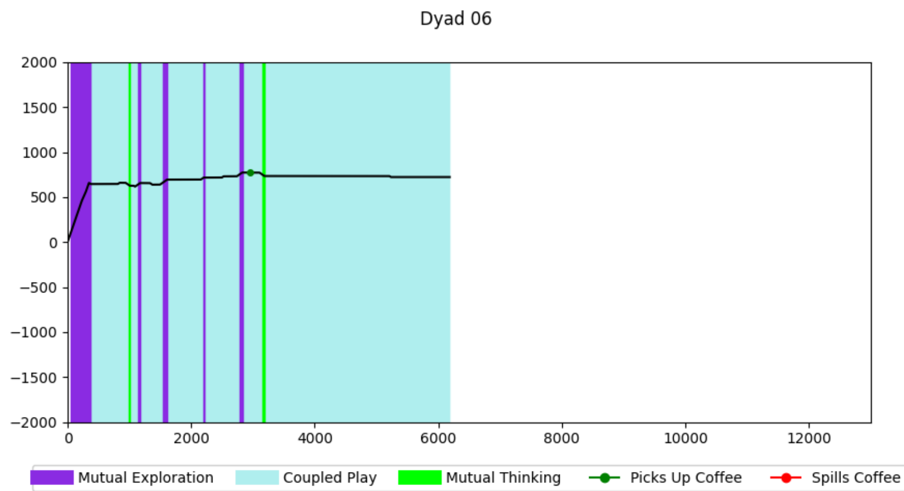





Dyad 03
2000
1500
1000
500
0
−500
−1000
−1500
−2000
0
2000
4000
6000
8000
10000
12000
Mutual Exploration
Coupled Play
Mutual Thinking
Picks Up Coffee
Spills Coffee


Dyad 04
2000
1500
1000
500
0
−500
−1000
−1500
−2000
0
2000
4000
6000
8000
10000
12000
Mutual Exploration
Coupled Play
Mutual Thinking
Picks Up Coffee
Spills Coffee


Dyad 05
2000
1500
1000
500
0
−500
−1000
−1500
−2000
0
2000
4000
6000
8000
10000
12000
Mutual Exploration
Coupled Play
Mutual Thinking
Picks Up Coffee
Spills Coffee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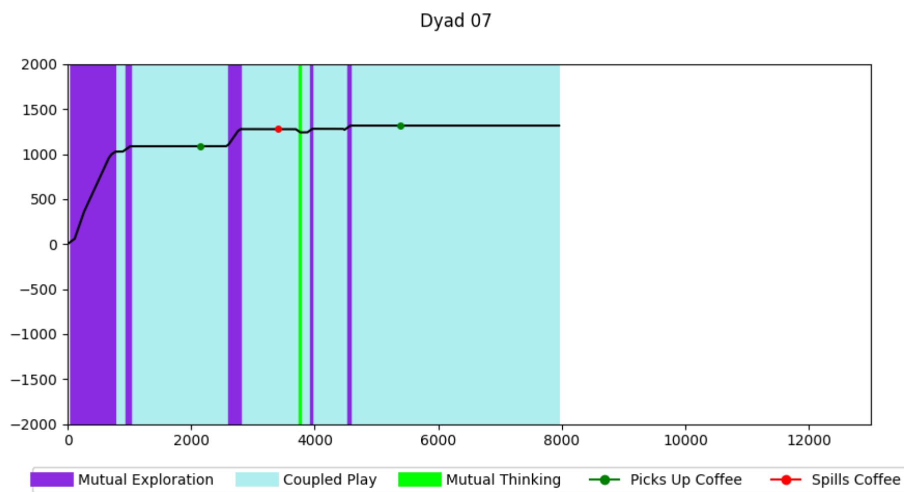
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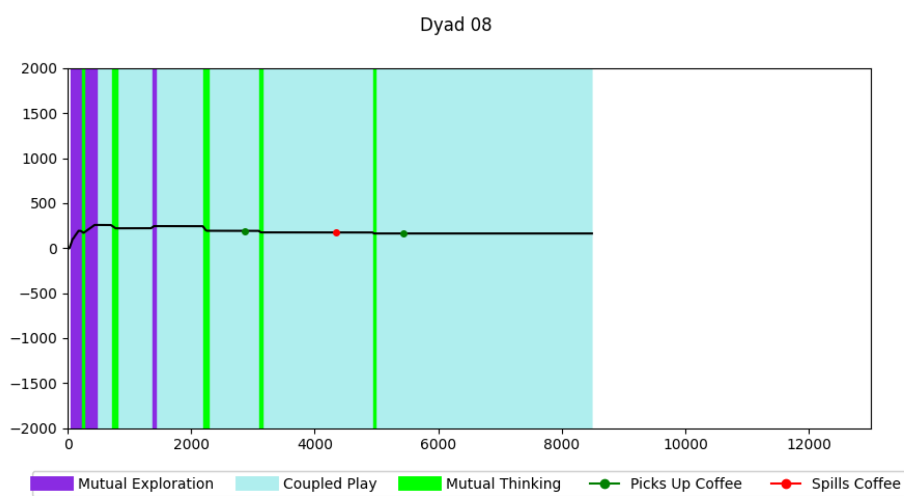
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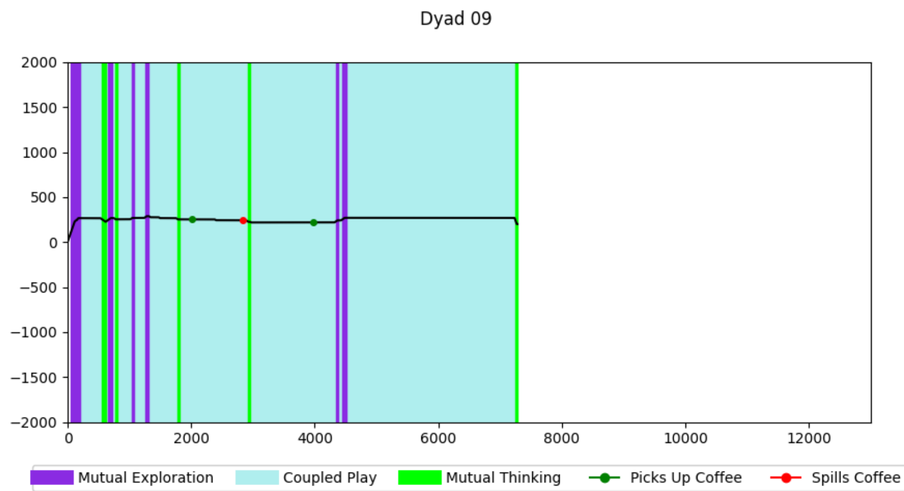
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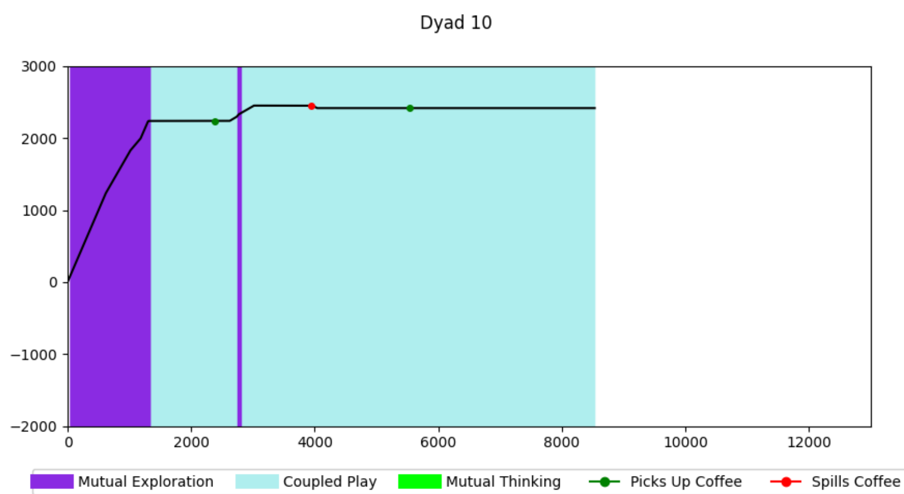
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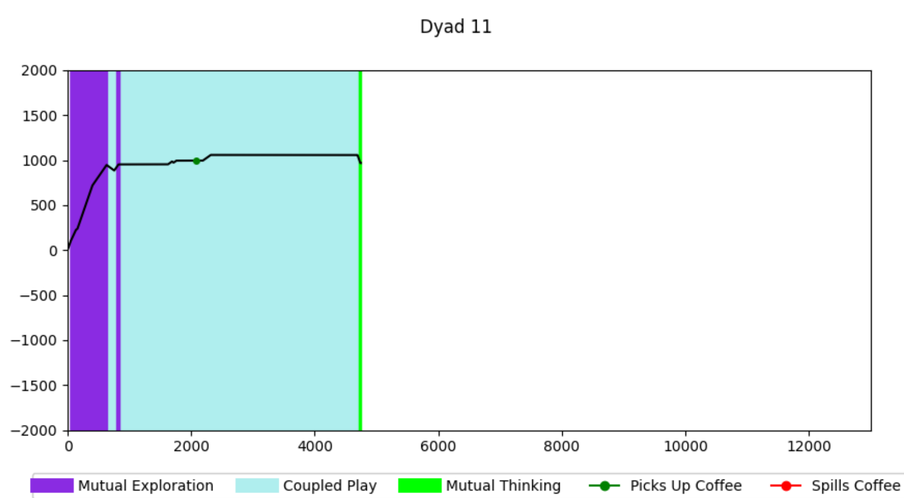
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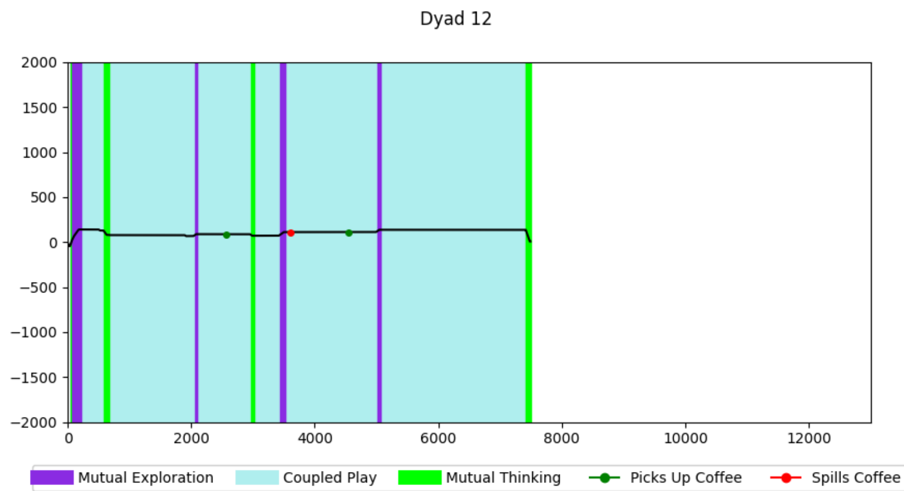
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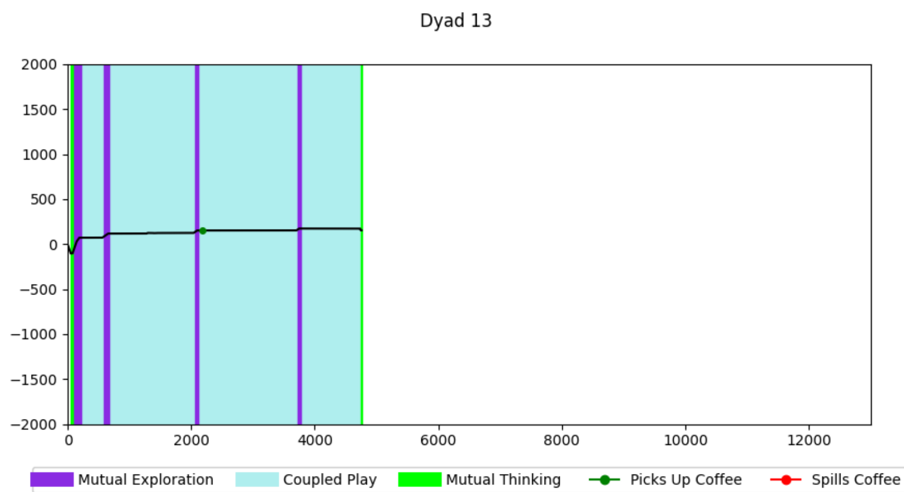
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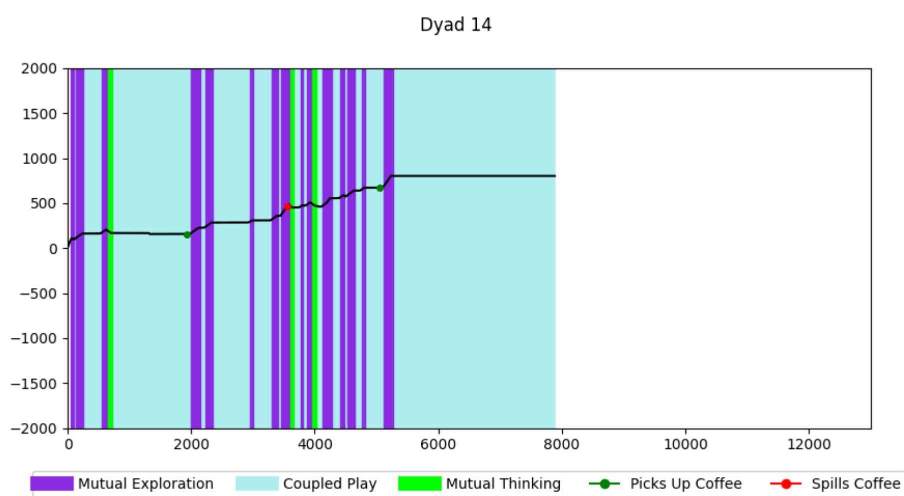
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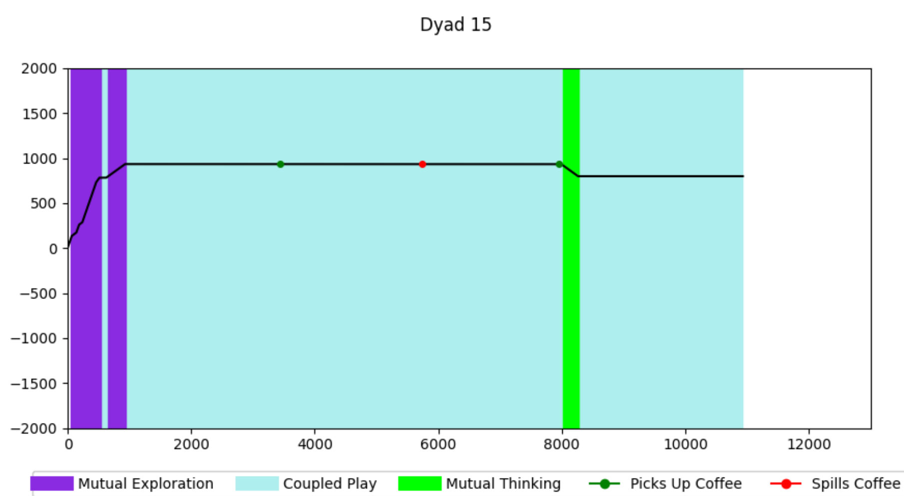
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