

# Out of Tune: Discord and Learning in a Music Programming Museum Exhibit

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## ABSTRACT

Museum visitors often come into the museum space receptive to exploring new ideas, and this may encourage members of visitor groups to be supportive and cooperative when engaging together with exhibits. However, as participant groups explore the concepts of the exhibit, interruptions, conflicts, or disagreements may result. We collectively label this social tension as *discord*. This paper studies discord among family groups interacting with *TuneTable*, a museum exhibit designed to promote middle school students' interest in and learning of basic computing concepts (e.g. loops, conditionals) through music programming. We analyzed video recordings of each participant group and found that discord often appears alongside three markers of high engagement: a) complex physical manipulation of exhibit components; b) conversation demonstrating an in-depth understanding of how the exhibit works; and c) instances of collaboration between group members. Our findings suggest that certain types of discord could potentially be indicators of productive learning experiences at museum exhibits related to computing. In addition, when designing informal learning experiences for computing education, our findings suggest that discord is a potential trigger for deeper engagement that warrants further exploration.

## Author Keywords

CS education, computing education, co-creative, discord, music-making, collaboration, informal learning, museums

## CSS CONCEPTS

- **Social and professional topics ~ Professional topics ~ Computing education ~ K-12 education**
- **Social and professional topics ~ Professional topics ~**

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IDC '20, June 21–24, 2020, London, United Kingdom

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<https://doi.org/10.1145/3392063.3394430>

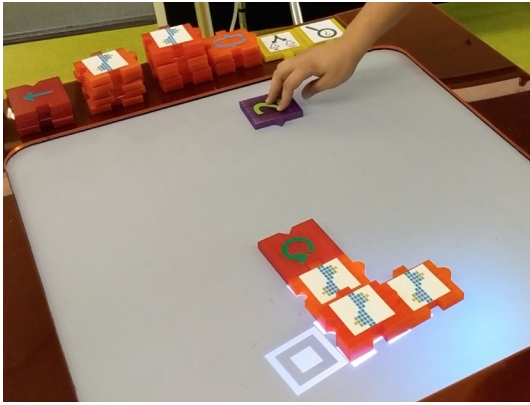
**Computing education ~ Informal education**  
• **Human-centered computing ~ Human computer interaction (HCI) ~ HCI design and evaluation methods**  
~ **Field studies**

## INTRODUCTION

*Discord*—a term we use to refer to social conflicts such as disagreement, interruptions, or disruptions to others' play—often occurs when individuals are collaborating together on a task involving shared resources. Discord can occur in any learning environment, but is likely more prevalent in informal spaces like museums, since these spaces tend to involve more group collaboration and negotiation of shared resources [1].

While discord is often seen as something negative to be avoided or quickly resolved in learning environments [2], research on classroom learning in a variety of domains has shown that certain types of discord can be productive and encourage learning, motivation, and interest development, especially in activities (like programming) that involve creative problem solving [3]–[5]. Increased discord may also be indicative of a more collaborative learning environment, and these types of environments have been shown to foster motivation and interest development in computing, particularly amongst underrepresented groups [6]–[8]. Despite these findings, there is limited research investigating the role of discord in computer science (CS) learning, which the research community could benefit from understanding further in pursuit of broadening participation and recruitment in computer science.

This paper attempts to contribute to a better understanding of the role that discord plays in CS learning experiences, particularly in informal learning spaces. We investigate this through an analysis of how discord relates to learners' intellectual, social, and physical engagement with *TuneTable*, a museum installation designed to encourage learning and interest development in CS. We begin by describing *TuneTable* and then present a video analysis study that examines family group coding sessions with *TuneTable*. We conclude with a discussion of the results from this study.



**Figure 1. The *Blockhead* programming language. The chain playing on the table consists of three sample blocks and a loop function block.**

### MUSICAL PROGRAMMING WITH TUNETABLE

*TuneTable* (Figure 1) is an interactive tabletop museum exhibit in which participants can co-create (i.e. collaboratively create) music using computing concepts. The table is designed to encourage collaboration, and it is targeted at family groups with middle school age children. Our research agenda with *TuneTable* (extending beyond the scope of this paper) has three primary goals: 1) introduce visitors to a high-level understanding of rudimentary computing concepts; 2) expand perceptions of computing by introducing computing concepts in the context of a creative domain (i.e. music); and 3) foster interest in computing. *TuneTable* builds on a variety of prior work in the IDC community that has explored how to design tangible programming environments to promote CS education in informal learning spaces [9]–[11].

Visitors interact with *TuneTable* using puzzle-piece shaped tangible blocks (Figure 1). Each block has a unique fiducial marker on the bottom of it that is read using reacTIVision<sup>1</sup> computer vision technology. Individual blocks, connections between blocks, and finger placement are detected and interpreted by reacTIVision<sup>1</sup>.

Users can interact with *TuneTable* using a bespoke programming language called *Blockhead*. Blocks can be placed on the table and joined together to make chains. When a *sample block* is placed on the table, a ‘play head’ is spawned (see Figure 1). Visitors can tap the play head with their finger to play the sound sample that the block is associated with. Sample blocks can be connected together to create a tune (i.e. a chain of consecutively played music samples). *Function blocks* can also be added to chains to create a subroutine. Function blocks reflect common computing concepts such as loops, conditionals, and “go-to” statements. For example, a loop function block connected to a sample block would make the sound sample repeat. More

detail on the functionality of *TuneTable* and the *Blockhead* programming language can be found in [12].

### RELATED WORK

Existing literature has looked at different types of discord/conflict and their relationship to 1) learning and 2) interest development (two of the *TuneTable* project’s core research goals). We examine this literature as well as related work on discord in informal learning spaces like museums. We explore literature relating to a variety of different definitions of discord.

#### Discord and Learning

Research into teaching strategies in computer science has shown that positive motivational feedback, such as praise for correct solutions and reassurance for incorrect ones, while beneficial for increasing a student’s perceived self-efficacy, often detracts from learning gains [13], [14]. In addition, studies examining creative problem solving have shown that small groups are more likely to reach a high quality solution when argument is emphasized rather than agreement [3]. Such results taken together suggest that harmonious social relations might foster complacency, whereas discordant interactions can incentivize a problem solver to push beyond an acceptable solution to an exceptional one.

Not all discord benefits learning equally, however. Johnson and Johnson [2] argue that *constructive controversy*—a type of discord in which individuals hold differing and incompatible information, ideas, or opinions but aim to reach an agreement—is an example of beneficial conflict. During constructive controversy, exposure to differing viewpoints produces conceptual conflict, thus prompting epistemic curiosity and subsequently a reconceptualization of the issue at hand [3]. Such a positive outcome of conflict exemplifies the cooperative goal context: one which utilizes open-mindedness and rational thinking to synthesize a superior argument from opposing positions [3]. Cooperative contexts contrast with competitive ones, such as debate, characterized by an unwillingness to compromise and rejection of opposing information. Research has shown that cooperative conflict is more effective than competitive conflict, avoidance of conflict, or working alone at reaching high quality decisions, improving cognitive reasoning, taking new perspectives, and changing attitudes (see [3] for an overview of studies on this topic).

#### Discord and Interest Development

Research on interest formation further distinguishes the differences between productive and unproductive conflict. Hidi and Renninger state that early developing interests are situational in nature and are subject to external factors or triggers [15]. In the case of museum experiences, these triggers may include characteristics such as the exhibit design, the topic being discussed, or the social dynamics of the visitor group.

<sup>1</sup> <http://reactivision.sourceforge.net/>

Certain types of discord have been found to negatively affect interest development—for instance, Renninger et al. found that group work was less likely to trigger interest when members of the group did not get along [16]. In contrast, other types of discord such as the aforementioned constructive controversy can be more effective than debate, avoidance of conflict, or individual problem solving at motivating continued learning [3]. Taken together, these findings suggest that not getting along with group members—and the negative emotions associated with such conflict—is not the same thing as the discord that arises during productive collaborations. For instance, group members that dislike each other may choose to disengage from a task rather than collaborate with each other, minimizing opportunities for constructive controversy or otherwise discordant interactions.

### **Discord, Museums, and CS Education**

Research on learning in museum settings often draws on Piaget’s theory of cognitive conflict, in which exposure to new information that conflicts with a child’s existing understanding of the world forces reevaluation and leads to learning [1], [17], [18]. However, the social nature of museums better lends itself to Doise’s *socio-cognitive conflict hypothesis*, an elaboration on Piaget’s model which acknowledges the impact of the social environment on a child’s learning [1], [17], [19]. This hypothesis proposes that child-parent interactions are more conducive to learning when the parent engages in argument or debate than when they simply give the child the correct answer—in other words, a discordant relationship induces cognitive conflict and subsequently fosters learning. Empirical research has indeed shown that the museum exhibits which generate the most debate talk also result in the largest learning gains for children [1], [17]. While this relationship is only correlational, it may indicate that designing to promote certain types of discord could be beneficial for learning.

In addition to traditional learning, museum environments also encourage creative problem solving (a skill central to computational literacy [20]), as they foster many social conditions conducive to creativity: exposure to diverse individuals and points of view, promotion of the exchange of ideas, and a focus on innovation and invention [21]. However, finding a high quality and creative solution often requires an iterative process involving rejection of initial lower quality solutions [3], and under harmonious conditions people are unlikely to search for an alternative once an acceptable solution has been proposed [5], [13]—it is the disagreement generated by discord that disrupts complacency and motivates creative inquiry. Despite the creative nature of the museum space, research on constructive controversy and other beneficial forms of conflict has focused mostly on structured classroom learning, and the impact of discord on problem solving in informal learning environments remains a relatively unexplored topic.

## **METHODOLOGY**

Prior work indicates that discord plays an important role in creative problem-solving, learning, and interest development, but there has been little research investigating the role that discord plays in learning about computing, particularly in informal spaces. In this section, we describe a study that we conducted in order to better understand family group interactions with *TuneTable* and how they relate to learning and interest development in CS. The analysis we present in this paper focuses specifically on examining the role that discord plays in these interactions.

We observed participant interactions with *TuneTable* at the Museum of Science and Industry Chicago during two different data collection sessions—one in July and one in November of 2017. Members of our research team recruited a total of 31 groups of middle-school (i.e. 10-14 year old) children and their parents to interact with *TuneTable*, which was installed in a classroom workspace in the museum. Participant interactions with the exhibit were video recorded from two different perspectives (top and side view). We collected demographic surveys from each participant group in order to better understand group composition. The study setup is discussed in more detail in [12].

Of the 112 total participants in the study, 40 were adults and 72 were children. Most (57%) of the children fell in the target age range of 10-14 years old. All but four sessions were composed of members of a single family. Adult family members were actively engaged in 28 out of the 31 interactions. In all cases, a facilitator from the research team was standing nearby if participants had questions. Facilitators rarely intervened in interaction but did briefly engage in nine of the sessions. In addition, all but five groups received a demonstration of table components at some point prior to or during their interaction. Group size varied, although most (27/31) groups had under five members. There were 11 dyads, 7 triads, and 9 groups of four members.

Measuring learning and interest development in museum settings is a challenging problem, as traditional metrics like lengthy pre/post tests or interviews can be obtrusive in a leisure environment where participants have limited time to explore a large exhibit space [22], [23]. Observation and video analysis is one common way of understanding whether participants are engaging in patterns of engagement and dialogue that can lead to learning and/or interest development [22]–[24]. We drew on this method, conducting a video analysis of the recordings of participant interactions with *TuneTable*.

We used Humphrey et al.’s Active Prolonged Engagement (APE) framework as a jumping-off point for our video analysis, as it is an established metric for understanding participant interactions with open-ended, co-creative museum exhibits like *TuneTable* [25]. Humphrey et al. consider four aspects of participant engagement with museum exhibits—physical, social, intellectual, and emotional. While not specifically focused on CS learning,

the four components of the APE framework capture patterns of socioemotional engagement that can lead to increased interest development in CS (e.g. collaboration) as well as patterns of physical and intellectual engagement that indicate participants are engaging with the exhibit and the embedded computational concepts in a complex way.

The APE framework has several existing video codes for each of type of engagement (physical, social, intellectual, emotional), but when applying these codes in practice, we found that they were often too general and subjective to be applied reliably by multiple coders. We therefore used APE as a guiding framework for a deductive thematic analysis [26] of the video data and developed an extended and more specific codebook for video analysis [12]. Our final codebook consists of a set of 18 codes, organized according to the four categories of the original APE framework. For the purposes of this paper, we describe only a subset of the final codebook (summarized in Table 1). More specifically, we do not describe our codes for the emotional component of the APE framework because they were not relevant to the scope of this paper, which is focused on the relationship between discord and indicators of high engagement with computational concepts. The codebook we developed was used to better understand participant interactions with *TuneTable* and specifically to examine the relationship between social discord and other types of physical, intellectual, and social engagement.

### Codebook for Video Analysis

#### Social Engagement

Humphrey et al. define *social engagement* as “the many ways in which visitors influence each other’s experiences at exhibits” [27]. The original APE framework created two five-point scales for coding for social engagement: *independence* to *working collaboratively* and *harmony* to *conflict*. In our coding scheme, we improved coder reliability by creating a series of *binary* scales for social engagement (*independence* vs. *collaboration*, *harmony* vs. *conflict*) and—based on the results of our thematic analysis—provided more concrete, observable definitions for abstract concepts like harmony.

Our thematic analysis also revealed an additional perspective to consider when coding for social engagement. We added *active/passive* vs. *equal partners* to the framework based on our thematic analysis, which revealed a variety of teaching and leading/following social behaviors that were not captured by the APE framework’s existing two scales. Each of these three binary scales is described in more detail below.

As mentioned in the introduction, we define *discord* as interrupting, stealing, or working in another person’s ‘territory’ (if it disrupts someone else’s apparent goals/plans), or refusing/ignoring an adamant request. This does not necessarily have to be associated with a negative emotional response. We chose to use the term *discord* rather than *conflict* because conflict can have more emotionally

charged connotations. In addition, *conflict* refers to a more dialogue-focused and structured classroom experience in the literature (e.g. [3]). To support the identification of productive discord, we created a binary scale: *discord* vs. *harmony*. *Harmony* means that all participants are working together in the absence of discord. This does not necessarily mean they are working together joyfully [27].

We say an interaction is *collaborative* if at least two members of the group are actively working towards a constructive, shared goal (e.g. working on a sound chain together or verbally discussing plans to modify a shared chain). *Independent* play occurs when no one in the group is working collaboratively.

An *active/passive* relationship between the group members indicates that one or more members of the group have taken on an *active* role, and one or more members of the group have taken on a *passive* role. An *active* group member may be teaching or directing/suggesting the action. A *passive* group member may be listening/observing/doing what they are told or simply not taking part in an active role. In an *equal partners* relationship, either no one in the group has taken on an active role, or everyone has taken on an active role.

Social	S:Discord S:Harmony
	S:Collaborative S:Independent
	S:ActivePassive S:EqualPartners
Intellectual	I:SeekingKnowledge I:SharingKnowledge I:ApplyingKnowledge
Physical	P:IsolatedManipulation P:InvestigativeManipulation P:IntegratedManipulation

**Table 1. Summary of codebook by category**

#### Intellectual Engagement

Humphrey et al. define *intellectual engagement* as dealing with “the connections visitors make to existing knowledge during their interaction, the conceptual understandings [they gain], and the questions they have” [27]. Based on our data analysis, we break down intellectual engagement into three distinct categories: *seeking knowledge*, *sharing knowledge*, and *applying knowledge*. *Seeking knowledge* highlights moments when participants are attempting to fill gaps in their current understanding of the exhibit’s functionality (e.g. asking about aspects of the exhibit or demonstrating curiosity or confusion). *Sharing knowledge* reflects moments when participants develop a mental model of the exhibit and are able to share this knowledge with their group members (e.g. sharing observations or explanations about the exhibit). *Applying knowledge* describes moments when participants

demonstrate that they have a strong understanding of the way the exhibit functions by applying and relating their knowledge to the exhibit (e.g. proposing a solution to a problem, formulating a plan for group action, or referencing prior knowledge). While learning can occur during all three stages of intellectual engagement, we see the progression from seeking to sharing to applying knowledge as indicative that the participant is engaging with the exhibit and embedded computational concepts on a more complex level.

Code Category	Gwet's AC1
Intellectual	.69
Social	
Active/Passive	.65
Discord/Harmony	.93
Independent/ Collaborative	.81
Physical	.92

**Table 2. Inter-rater reliability Gwet AC1 scores for all coding categories (social codes are broken down by sub-category)**

#### Physical Engagement

Physical engagement refers to the ways in which visitors interact physically with an exhibit by engaging in hands-on manipulation of the tangible aspects of the installation. This is slightly narrower than the definition in the original APE framework, which also includes factors like where the visitors are standing in relation to the exhibit [27]. We chose to focus on this narrower scope because 1) the video capture for *TuneTable* was restricted to the table and the immediately surrounding area in order to protect the privacy of passersby; and 2) we wanted to focus on the participants' engagement with computing concepts, which were materialized in the blocks on the table. We describe three of the codes we developed to describe visitors' physical engagement here: *isolated manipulation*, *investigative manipulation*, and *integrated manipulation*. *Isolated manipulation* refers to moments when participants are physically interacting with the exhibit, but only with isolated components (e.g. testing out a single sample block). *Investigative manipulation* refers to moments when participants are beginning to methodically explore how the exhibit works using physical means (e.g. chaining together multiple sample blocks). *Integrated manipulation* refers to moments when participants are physically manipulating aspects of the installation in a complex way (e.g. connecting sample and function blocks to make complex musical compositions). These codes can be further explored in [12]. Similar to intellectual engagement, opportunities for participants to engage with computational concepts increase as participants move from isolated to investigative to integrated manipulation.

#### Coding Process

We analyzed videos using the ATLAS.ti coding software. When analyzing videos, we established a fixed unit of analysis in order to avoid discrepancies resulting from subjective variability in both the unit of analysis (*when* the event is taking place) and the code (*what* is taking place). Each video was divided into a series of 10 second segments and codes were applied to each one of these segments. For social codes, one code per binary scale was applied to each unit of analysis. For example, one ten second segment might be coded with *S:Discord*, *S:Collaborative*, and *S:Active/Passive*. Multiple physical codes could be ascribed to each unit of analysis, if multiple types of physical interaction were taking place within the segment. For example, one ten second segment might contain both *P:IsolatedManipulation* and *P:InvestigativeManipulation* codes if one participant was testing out individual sound blocks while another worked on a chain. Finally, for intellectual codes, which rely more on the content of verbal utterances, we transcribed the videos and ascribed one code per each line of dialogue. We did this because multiple lines of dialogue often appeared in a single 10 second segment.

We calculated an inter-rater reliability (IRR) score for each type of engagement using a subset of the video data in order to determine whether the code definitions and coder training were adequate. Two coders were used to establish IRR for each category, although coder pairs differed from category to category. For each type of engagement, the coders analyzed four different participant interaction sessions that were each approximately 10 minutes in length (two from the July study and two from the November study). A stratified random sampling of 157 units of analysis from these four videos was used to calculate an IRR score. The size of our sampling was determined using Lacy and Riffe's [28] method for calculating minimum sample sizes needed to establish reliability.

We use Gwet's AC1 [29] statistic to calculate IRR scores, due to a recognized issue with Cohen's Kappa when it is calculated for data in which certain events (e.g. discord) are rare [30]. The AC1 statistic is an alternative to Cohen's Kappa that corrects for this issue while still accounting for chance agreement [29]. IRR scores for each of the categories of engagement are reported in Table 2. All scores are classified as either substantial agreement (.61 to .80) or almost perfect agreement (.81 to 1.00) according to [31].

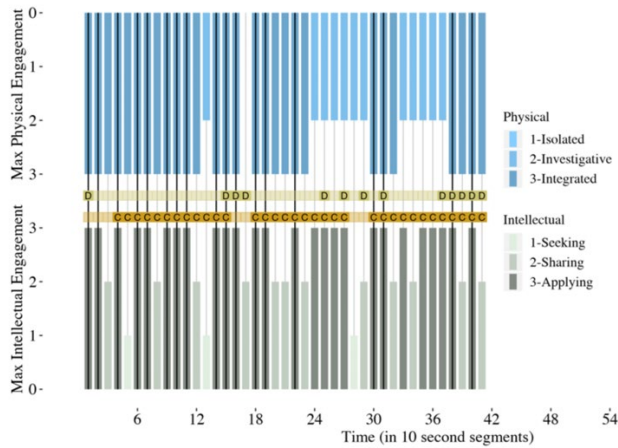
#### RESULTS AND ANALYSIS

We analyzed 31 recordings of participants collaboratively coding music on *TuneTable* ranging from 4 minutes 20 seconds to 12 minutes 20 seconds (M=9:00; SD=1:56). The length of the videos reflects the length of time participants interacted with the installation—although it should be noted that these do not reflect interaction times in-the-wild, as all participant groups were asked to participate in a ~20 minute study. Videos were trimmed prior to analysis to include only the period of time that participants interacted with the table



as a family—introductory comments, the consent process, and post-interaction questions were not included in the video analysis and are not factored into the video length.

An initial examination of correlation scores (measuring the strength of the relationship between two variables using *Kendall's tau*) between codes suggested that *S:Discord* may be correlated with codes indicative of higher levels of engagement (e.g. *P:IntegratedManipulation*, *I:ApplyingKnowledge*). We decided to more deeply investigate this relationship in the following analysis.



D = Discord; C = Collaborative  
Black line = highest physical engagement (*P:IntegratedManipulation*) and highest intellectual engagement (*I:ApplyingKnowledge*)

**Figure 2.** This figure shows the codes associated with each time segment in one recording. For example, time segment 31 represents *DesiredInteraction*. This segment shows the highest intellectual engagement (Level 3, *I:ApplyingKnowledge*) and the highest physical engagement (Level 3, *P:IntegratedManipulation*). The two rows of tabs in the center of the plot indicate segments that are also coded as collaborative (C = *S:Collaborative*) and discordant (D = *S:Discord*). Segments 31, 38, and 40 represent both *DesiredInteraction* (coded as highest intellectual engagement, highest physical engagement, collaborative) and *S:Discord*.

### Discord and High Engagement

We first sought to understand whether there were instances across recordings in which participants reached desired states of engagement. That is, we wanted to know whether participants had become familiar with the exhibit components, were intellectually engaging with the exhibit at a high level, and were collaborating with each other. We operationalized this desired state of engagement as segments coded with the highest level of physical engagement (*P:IntegratedManipulation*), the highest level of intellectual engagement (*I:ApplyingKnowledge*), and instances in which members of the group were working collaboratively (*S:Collaborative*). We created a composite variable (*DesiredInteraction*) to represent this combination of codes, illustrated in Equation 1.

### *DesiredInteraction*

$$= P: IntegratedManipulation \\ + I: ApplyingKnowledge \\ + S: Collaborative$$

### Equation 1

We found that 26 of 31 groups displayed *DesiredInteraction* at some point during their interaction. The 26 groups displaying *DesiredInteraction* spent an average of 36% of their time in this state; group time spent in the *DesiredInteraction* state ranged from 13% to 65%. Further, we found a significant positive correlation between *DesiredInteraction* and *S:Discord* ( $r_t = 0.15$ ,  $p < .001$ ), indicating that desired group interaction might also be accompanied by social friction. Figure 2 shows a visualization of the codes for one example group that exhibited *S:Discord* at the same time as *DesiredInteraction*.

We next sought to understand whether the correlation between *DesiredInteraction* and *S:Discord* occurs by chance using a  $\chi^2$  analysis.  $\chi^2$  analyses compare the pattern of responses between two variables to determine whether the observed responses are significantly different from expected responses if the variables were independent of one another. The results show a significant association between *DesiredInteraction* and *S:Discord* ( $\chi^2 = 35.3$ ,  $p < .001$ ).

Seeing both a significant correlation and a  $\chi^2$  association, we explored instances in which *S:Discord* appears with the individual variables that comprise *DesiredInteraction*. *S:Discord* is rare, occurring in less than 10% of all coding segments (156 out of 1,691 10-second segments), but it is also consistent, appearing in 74% of all recordings (23 of 31). Table 3 shows *DesiredInteraction* co-occurs with *S:Discord* 40% of the times that *S:Discord* occurs. Table 3 also shows the number and percentage of times that the codes and code combinations comprising *DesiredInteraction* appears. *S:Discord* predominantly appears alongside the three codes that comprise *DesiredInteraction*—*S:Collaborative*, *I:ApplyingKnowledge*, and *P:IntegratedManipulation* (between 69% and 82% of the time). *S:Discord* appears with the combination of *P:IntegratedManipulation* and *I:ApplyingKnowledge* 59% of the time.

The results from our correlation,  $\chi^2$ , and co-occurrence analyses cumulatively suggest that discord occurs alongside desired engagement states. Fostering collaboration is one of the key design goals behind *TuneTable*, and integrated manipulation and applying knowledge represent the most complex/advanced levels of physical and intellectual engagement (respectively) captured by our coding scheme. Based on the findings from this exploratory analysis and the existing literature discussed in Related Work, we hypothesize that discord may be a marker of deeper physical, intellectual and social interaction and that it may indicate social behavior that represents more meaningful engagement and understanding.

Codes	n	% co-occurrence w/ discord
S:Collaborative	128	82%
P:IntegratedManipulation	127	81%
S:Collaborative + P:IntegratedManipulation	113	72%
I:ApplyingKnowledge	108	69%
S:Collaborative + I:ApplyingKnowledge	94	60%
P:IntegratedManipulation + I:ApplyingKnowledge	92	59%
DesiredInteraction (P:IntegratedManipulation + I:ApplyingKnowledge + S:Collaborative)	84	54%

**Table 3. Co-occurrence of discord (n=156) with codes comprising *DesiredInteraction***

### Types of Discord

We further examined the interactions that were occurring around moments of discord in order to contextualize our results. We re-watched each of the moments of discord that we coded in the videos and created written descriptions of the events leading up to and following the moment of discord. We then thematically grouped the descriptions, resulting in a list of several types of discord that occurred in participant interactions with *TuneTable*. We describe these types of discord in the remainder of this section (summarized in Table 4) and present correlations between each type of discord and the codes comprising *DesiredInteraction*.

As noted in the literature [2], [16], not all types of discord contribute productively to learning, creative problem solving, and interest development. We define *productive discord* as discord that has the potential to inspire new creative directions, foster collaboration, and/or spur a cooperative discussion of ideas. The literature presented in Related Work suggests that productive discord is more likely to foster learning and interest development in CS, and that it may be characterized by a cooperative discussion of opposing ideas, the introduction of cognitive conflict by a parent or facilitator, or iterative creative ideation involving multiple group members. *Unproductive discord* is discord that does not clearly lead to any of the aforementioned opportunities for learning/interest development. Unproductive discord is not necessarily counterproductive to learning/interest development, it just does not directly contribute to it. The literature presented in Related Work suggests that unproductive discord may be characterized by competition, an unwillingness to compromise, outright rejection of opposing information, or group members not getting along with each other. In this section, we identify some types of discord (conflicting goals, opposing hypotheses) as being productive for learning and creative

exploration and others (taking control, limited space/materials, disruptive disturbances) as being unproductive (Table 4).

Discord Type	Productive?	Number of instances (n=156)
Conflicting Goals	Yes	70
Opposing Hypotheses	Yes	16
Taking Control	No	18
Limited Space/Materials	No	19
Disruptive Distractions	No	16
Other	N/A	17

**Table 4. Breakdown of discord instances by type and productivity**

### Conflicting Goals

The most common type of discord that occurred resulted from group members' *conflicting goals* (n = 70 out of 156). In some of these instances, two or more group members held different creative goals for the interaction—in other words, they each had a different plan in mind for what they wanted to create. For example, one family (Case 1) decided mutually that they needed to conclude their sound chain with a block. One of the children suggested ending it with a function block, but the other child disagreed, saying “Wait no, it needs one of these,” and put down a sample block. The two children had different goals as to how their collective creation should progress. In this example, discord manifests itself as a conversation in which two or more participants negotiate competing goals for a communal composition. The group ends up deciding to use both blocks, but in different places in the chain. This new, cooperatively developed creative direction would not have been possible without the preceding instance of discord. The role of goals and plans in generating discord is corroborated by our finding that *I:ApplyingKnowledge* is correlated with *S:Discord*.

In other cases, conflicting creative visions looked more like interruptions to individual pursuits. For example (Case 2), a boy was attempting to touch a play head in the middle of the table, and a girl reached over to push his hand out of her way in the interest of grabbing a sound block from the other side of the table. The girl was upset, telling the boy that “[he] stopped my [chain].” The boy, in response, said “yeah, because I need to test out mine first.” Because the two participants were focused on their own work, they were unable (or unwilling) to acknowledge the work that was being undertaken by others. However, it is also notable that they were so deeply engaged in creating and testing their compositions that it resulted in a social conflict—the discord seems to result from a disruption to the visitors' creative flow [32]. Research on user interaction with public displays has found that in addition to being indicative of high levels of

engagement, conflicts like these can in some cases inspire new creative directions and/or spur future collaboration [33]. In this case, the group ends up sharing each of their individual compositions with each other and offering commentary and suggestions for improvement (e.g. “This is mine!”; “Oo, [name], yours repeats!”).

In other scenarios, one group member (often an adult or older child) was pursuing a learning-related goal while the other group member(s) were more focused on creating tunes. In one group (Case 3), one of the children started to move the inspector block (a block that could be placed next to other blocks to learn about their functionality) off the table. She was stopped by her mom, who said, “Stop, I want to see what this does”. The mother proceeded to put a new block down next to the inspector block to learn about its functionality. The mother was trying to learn more about different blocks’ functionality, whereas the daughter wanted to move on and work on her composition. In another case (Case 4), a group of children were attempting to build a complex chain, but they lacked understanding of how the more advanced function blocks worked. As they tried to force incompatible blocks together, their father told them to stop and make a chain with only sound blocks, advising that they “start [simple] and then add [more complex blocks].” While the kids were haphazardly placing blocks on the table to create a song, the father imposed a more structured learning goal.

In all of these cases, the discord generated appears to be the result of a high level of engagement by participants that are invested in their creative composition and/or learning experience. In addition to being indicative of engagement, discord resulting from conflicting goals can also lead participants to potentially collaborate and explore new creative directions (Case 1, 2), learn about computing concepts and exhibit components (Case 3), and create more structured and goal-oriented learning experiences (Case 4). This type of discord is productive due to its potential to foster collaboration and iterative creative ideation. These findings are supported by our correlation analysis, which found that moments of discord classified as *conflicting goals* were significantly positively correlated with moments of *I:SharingKnowledge* ( $r_{\tau} = 0.07$ ,  $p < .001$ ), and *I:ApplyingKnowledge* ( $r_{\tau} = 0.11$ ,  $p < .001$ ), the two higher levels of intellectual engagement.

#### Opposing Hypotheses

We also observed discord arising as participants were learning about the different function blocks on the table and presenting opposing hypotheses as to how the table/computing concepts worked—we refer to this as *opposing hypotheses* (n = 16 out of 156). This type of discord is similar to the *constructive controversy* that Johnson and Johnson observed in classroom dialogue [2]. For example, participants in one group (Case 5) wanted to loop their composition, and they placed the loop block (i.e. a block that would loop a sound sample for a specified number of times) on the table to test its function. When they were unsuccessful

(due to a technical malfunction), the boy suggested that perhaps an arrow block (i.e. a block that functioned as a “go-to” statement, jumping the playback a certain number of blocks in the specified direction) would have a looping function (“Maybe its this one [arrow block].”). The father responded and asserted that the loop block—not the arrow block—was appropriate for their goals (“No, no, this one [loop block] goes on and on and on and on”). These types of interactions—in which multiple group members suggest alternative hypotheses for how function blocks work—corroborate our finding that *S:Collaborative* and *P:IntegratedManipulation* both co-occur frequently with *S:Discord*. This type of discord is productive due to its potential to spur cooperative discussion, and is an example of socio-cognitive conflict that can lead to learning [19].

#### Taking Control

Certain moments of discord were caused by group members that tried to *take control* over whatever action was happening on the table (n = 18 out of 156). The play button on the table was sometimes difficult to trigger, and there were several scenarios (collectively referred to as Case 6) in which one participant swatted another participant’s hand out of the way to see if they could do a better job of hitting the button. In other cases, such as Case 7, one group member reached in and adjusted a block in someone else’s composition to ensure that it was connected properly. This form of discord was significantly positively correlated with *P:IntegratedManipulation* ( $r_{\tau} = 0.05$ ,  $p < .001$ ), and *I:ApplyingKnowledge* ( $r_{\tau} = 0.07$ ,  $p < .001$ ), but our observations indicated that interventions were usually brief, physical rather than verbal in nature, and seemed to be driven more by frustration with other group members than a coherent goal/plan. The lack of dialogue and competitive spirit present in most of these interactions suggests that this is an unproductive form of discord.

#### Limited Space/Materials

Some conflicts occurred as a result of *limited space or materials* (n = 19 out of 156). In one group (Case 8), a girl wanted to add an arrow block to her composition, but was directed by her mom to let her brother use it instead (“No, let your brother do that one”). The presence of additional arrow blocks would have resolved this issue. In other scenarios, physical space became an issue, with participants’ arms getting in the way of others’ compositions as they reached across the table (Case 9). A similar phenomena, referred to as *interference*, was also documented in Humphrey et al.’s research on APE exhibits [25]. Humphrey et al. found that interference limited participants’ ability to reach their full creative potential while interacting with exhibits [25]. However, arguing over materials may indicate that participants are motivated to pursue their creative goals (enough to create social discord), and conflicts over space could positively suggest that the tabletop territory is being fully utilized for creative exploration. This is supported by our correlation analysis that found that moments of discord classified as resulting from *limited space or materials* were



significantly positively correlated with *P:IntegratedManipulation* ( $r_t = 0.06$ ,  $p < .001$ ) and *I:ApplyingKnowledge* ( $r_t = 0.1$ ,  $p < .001$ ), the two highest levels of physical and intellectual engagement. However—unlike *conflicting goals*—the potential for *limited space/materials* to inhibit the exploration of new creative directions and/or cause competition over resources suggests that this is a form of unproductive discord.

### Disruptive Distractions

There were a few instances of discord that appeared to be both unproductive and not indicative of deep engagement—we refer to these instances as *disruptive distractions* ( $n = 16$  out of 156). For example, in several interactions (collectively referred to as Case 10), at least one child was well below the target demographic age range (our team made an effort to recruit middle school age visitors, but these individuals often had younger siblings that joined in the interaction). In these cases, much of the discord observed was a result of the youngest participant disrupting the group engagement with the table by grabbing blocks that were in use by other members of the group (either from the table or from the hands of another individual—resulting in exclamations like “Hey give mine!”), “Keep that there!”), “I need this!”) or demanding the attention or discipline of the adult monitoring the group (e.g. “Don’t just throw it [the block]”). Much of the discord in these cases stems from the fact that the youngest children were not capable of collaborating productively with the older members of the group, and therefore seemed to feel left out or ignored. Members of the group often redirected their focus from collaborations on the table to managing the child’s behavior. Moments of discord classified as *disruptive distractions* also have a significant positive correlation with *P:IsolatedManipulation* ( $r_t = 0.07$ ,  $p < .001$ ), the lowest level of physical engagement. The unwillingness to compromise and the competitive exclamations of frustration between participants indicate that this is an unproductive form of discord.

The many different types of discord identified in our video review suggest that although moments of discord can be indicative of deeper engagement and lead to increased learning dialogue and creative engagement (e.g. conflicting goals, opposing hypotheses), there are also certain types of discord that are less productive (e.g. taking control, limited space/materials, disruptive distractions). It is therefore important to pay attention to the contextual circumstances surrounding moments of discord.

## DISCUSSION

We found via video coding that discord frequently co-occurs with codes corresponding to markers of high engagement—including social collaboration, integrated physical manipulation of exhibit materials, and applying knowledge. We also observed in our case analysis that discord occurs for a variety of reasons, including as a result of conflicting goals (e.g. Cases 1-4), as part of learning dialogue (e.g. Case 5), as part of a social negotiation of control (Cases 6, 7), as a

result of territorial conflict over shared resources (e.g. Cases 8, 9), and due to interference from younger, less-engaged group members (Case 10). These findings—taken in conjunction with prior research on the topic—suggest a number of takeaways and design implications, which are described in the remainder of this section.

First, *discord appears to be an observable indicator of a high level of engagement with the computing concepts embedded in TuneTable*. While visitor learning can occur in all stages of physical engagement, opportunities for learning about computational concepts exist almost exclusively in the integrated manipulation stage (once the group has begun to use function blocks). The ability to quickly “apprehend” exhibit components is often a prerequisite for engaging with the learning goals of the exhibit [9], [34], and this is operationalized in our analysis as a participant group engaging in sustained interaction at the integrated manipulation level. It is also most apparent that visitors have developed an accurate mental model of the installation and the computational concepts embedded within when they are able to apply knowledge by proposing a solution to a problem or relating their interactions to prior experiences. This aligns with research on CS learning that suggests that activities like applying knowledge and creating novel programs are indicative of a higher level of understanding [35]. We found that instances of discord were correlated with markers of both integrated manipulation and applying knowledge.

One difficulty of coding video interactions in complex social environments like museums is finding phenomena in the video that are both *easily discernible* (which supports inter-rater reliability) and *important* because they represent a desirable characteristic or group interaction. We found that discord as a code is an easily observable interaction that tends to appear in moments when advanced engagement is taking place. This suggests that *discord could be an important marker to look for in CS-related exhibit evaluation in the future*. Of course, there may be many other easily discernible markers of desirable engagement in CS learning exhibits that may involve harmonious interaction as well.

Our case analysis revealed that *discord resulting from conflicting creative or learning goals may be indicative of a particularly high level of engagement*—one in which visitors are willing to break social norms to either build on their composition or test out a hypothesis (e.g. Cases 1-4). This may suggest that certain types of discord indicate moments in which the desire to understand or create becomes greater than the need to maintain social order. In these cases, participants may be engaged in creative *flow*, or a positive, absorbing creative experience in which participants possess a sense of individual control over the creative interaction [32].

Discord resulting from conflicting goals can also potentially lead to new creative directions as visitors collectively negotiate between their individual creative plans (e.g. Cases

1, 2). In the cognitive science literature, the term *distributed creativity* is used to refer to creative processes in which the final creative product is a result of group collaboration, and “no single participant’s contribution determines the result” [36]. Conflicting individual goals and the resulting negotiations have the potential to lead to the emergence of a collaborative group creation [36].

*Discord can also be indicative of productive learning dialogue.* Participant discussions of opposing hypotheses related to how the system works or how to solve a problem can potentially lead to a better understanding of alternative perspectives as well as increased curiosity/interest development (e.g. Case 5) [2]. This is supported by Doise’s socio-cognitive conflict hypothesis, which suggest that social interactions can lead to cognitive conflict, leading to reevaluation of ideas and learning [19].

Designers have found that learning dialogue and productive discussions can be fostered by introducing signage that includes thought provoking questions and follow-up content [34], [37]. For example, a sign for *TuneTable* might say “Can you make a sound sample loop three times?” or “What do you think the arrow block does?”. Depending on the setting, facilitators such as teachers, parents, or museum staff can also be equipped with discussion points to prompt conversation [38]. However, it is important that facilitators offer probing questions or thought provoking comments (e.g. “Cool tunes! Maybe you could find a way to connect them into one composition?”) as opposed to trying to explain how the table components work to participants, which may lead to reduced exploration, as children often assume adult’s explanations are “correct” and do not question them [1], [38].

There are also some types of discord that are less productive than the above. *Conflicts resulting from limited space or materials or disruptive disturbances from younger group members may hinder creative progress and/or learning* (e.g. Case 10). The literature on museum exhibit design suggests some ways to address these less desirable forms of “interference” [25]. For example, exhibits with a single shared workspace may benefit from the introduction of multiple stations in which visitors can exercise “individual control” over their compositions [25]. There is, of course, a balance to be struck between promoting collaboration and social interaction and allowing for a measure of individual control. A combination of individual and shared work spaces could help resolve this issue. Designing to support varying levels of engagement and/or incorporating peripheral, related activities that do not disrupt the main working space can also be useful for engaging young audiences in a productive way even if the core exhibit is targeted at an older demographic [39], [40].

## CONCLUSION

In this paper, we present an analysis of visitors’ physical, social, and intellectual engagement with *TuneTable*. Our findings indicate that moments of discord that occurred amongst visitor groups interacting with the table are

significantly related to collaboration and complex physical and intellectual engagement with the system. This may indicate that discord is a sign that productive learning dialogue is occurring at museum exhibits—a phenomenon that we also observed in our case analysis of the video data. These findings also suggest that designers may want to further explore how to support moments of discord in museum installations involving computing concepts.

## SELECTION AND PARTICIPATION OF CHILDREN

Families with children who appeared to be ~10-14 years old were recruited from the museum floor and asked if they wanted to participate in a ~20 minute study by interacting with a new exhibit. Participants were informed that they would be compensated with one \$10 Amazon gift card per child. Interested families were then led to a classroom separate from the museum floor, informed that their interactions would be recorded, and individually asked for verbal assent. After interacting with the exhibit alongside their parental guardian(s), children in the target age range answered follow-up questions about their experience while their parents filled out a demographic survey. Collected data is stored using secure cloud storage and un-anonymized data is not shared beyond the research team. University IRB approval was obtained for this study and data collection/analysis protocol.

## ACKNOWLEDGEMENTS

We would like to thank all past and present members of the *TuneTable* evaluation and design teams, especially Mirina Garoufalidis, Hannah Guthrie, Nylah Boone, Emily Bryans Anna Xambó, and Gerard Roma, without whom this research would not have been possible. We would also like to thank Aaron Price and the Museum of Science and Industry Chicago for supporting and providing an audience for this research. This project is funded by the National Science Foundation (DRL #1612644).

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