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Adapting Educational Technologies Across Learner Populations: A Usability Study with Adolescents on the Autism Spectrum

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Abstract

This paper reports initial results from a usability study conducted in the formative and user-centered design phase of a larger project to translate an existing, science-focused educational technology for neurotypical middle school students into a new, social-reasoning-focused educational technology for students on the autism spectrum. Participants in our study included both adolescents on the autism spectrum and typically developing adolescents, who were asked to complete the Betty's Brain educational-technology-based science activity as well as a social-reasoning movie question-answering activity. Results include qualitative observations of general student engagement and challenges as well as quantitative measures of performance and eye gaze, including key differences observed across our two sample groups, with the goal of informing the design and adaptation of future technology-based interventions. Our findings suggest specific considerations for designing educational technologies for adolescents on the autism spectrum, including 1) finding ways to help students follow instructional/tutorial portions of new technologies, especially when lengthy instructions and/or complex interfaces are involved; 2) proactively anticipating and finding ways to mitigate potential student episodes of frustration / dysregulation while using the technology; and 3) capitalizing on features of the technology found to be engaging/motivating for students.

Keywords: Autism; eye tracking; science reasoning; social reasoning; usability.

Introduction

Technology-based educational interventions are used in many subject areas and for many learner populations, but the same intervention "out of the box" may not be equally effective across students with different cognitive makeups, either within or across subject areas. At the same time, developing completely new technologies for every population and subject area would be infeasible, not to mention wasteful of resources invested and knowledge gained from prior efforts.

Thus, there are opportunities for high potential impact in carrying out intentional, systematic adaptations of existing educational technologies across learner populations and subject areas. However, to be successful, such adaptations call for not just the translation of curricular materials from one discipline to another, and corresponding studies of learning gains in the new domain/population, but also careful consideration of usability when moving from one learner population to another. Usability studies can facilitate the transfer of effective educational technologies across learner populations and subject areas by pinpointing potential wrinkles in the original technology and by suggesting helpful modifications to address these wrinkles.

Such usability studies are especially important in the context of designing interventions for autism, including studies that incorporate many modes of data collection and analysis such as different types of stakeholder interviews, eye-tracking, etc. (Barry et al., 2008; Weiss et al., 2011; Khan et al., 2013; Mei et al., 2014; Al-Wakeel et al., 2015; Casale et al., 2015; Hochhauser et al., 2015; Hussain et al., 2016; Mejía-Figueroa et al., 2016; Rosen et al., 2017; De Bruin et al., 2018; Eraslan et al., 2019).

Here, we study usability and engagement as part of a formative, user-centered design process in a larger project that aims to translate the *Betty's Brain* science education system (Leelawong & Biswas, 2008), designed and used to date for typically developing middle school students in general classroom environments, into a new intervention for teaching the-

Figure 1: **Screenshots of activities in our usability study.** Left: A one-hour module on forest ecosystems from the *Betty's Brain* science education technology (Leelawong & Biswas, 2008). Center and right: TV/movie clips from our social-reasoning QA activity, including animated (e.g., *Cooperation* short film) and live-action (e.g., *Hidden Figures*) clips; Table 2 lists all clips.

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ory of mind (ToM) and social reasoning skills to middle-school students on the autism spectrum.

Many individuals on the autism spectrum have difficulties with theory of mind (ToM) and social reasoning skills, which are important for many aspects of learning, communication, forming social relationships, etc. (Frith, 1994; Kaland et al., 2008; Peterson et al., 2009). Our own recent study of parent perspectives of particular challenges that their children on the spectrum face in social/relational domains echo these findings (Rashedi et al., 2020). Thus, there is a critical need for educational interventions to help individuals on the spectrum improve their ToM and social skills. A recent meta-analysis further noted that, "Perhaps surprisingly, a minority of included studies focused explicitly on training ToM skills" (Fletcher-Watson et al., 2014). The remainder targeted ToM precursor skills such as emotion recognition, joint attention, or imitation, and in many of these studies, improvements in the targeted precursor skill did not carry over into broader ToM or social reasoning abilities.

We see many parallels between the complex systems studied in STEM disciplines (e.g., ecosystems, physiology, etc.) and complex social situations: both involve many interacting agents or elements; both often have states that are hidden to an observer; both involve multi-layered, multi-directional causal connections; and both often contain apparent contradictions or ambiguities. Thus, at a high-level, our motivating question is: Can we reuse the work put into educational technologies already developed to teach reasoning about complex systems in STEM, by adapting these technologies to teach ToM and social reasoning to students on the autism spectrum?

In this paper, we report on an initial usability study conducted to investigate student performance and responses to 1) the Betty's Brain science education system (Leelawong & Biswas, 2008); and 2) a social reasoning activity involving watching short movie and TV clips and answering questions about the social content within them, similar in flavor to other recent film-based interventions

Methods

For our exploratory usability study, we invited adolescents to complete two primary study activities: 1) a roughly one-hour session using the *Betty's Brain* science education system (Leelawong & Biswas, 2008); and 2) a roughly one-hour session of social-reasoning-based question answering centered around a series of television and movie clips. Both activities were completed in a lab setting across two separate sessions. Participants were either on the autism spectrum (AS) or typically developing (TD) and ranged in age from 10 to 17 years. This study adhered to the procedures outlined in an institutional review board (IRB) approved protocol.

Additional study procedures included interviews with parents to discuss their child's typical usage and experiences with technology in their daily lives. Some brief findings from this parent interview component are included in this paper to give context for our current results; more detailed findings are reported elsewhere (Rashedi et al., 2020).

Participants

We recruited participants via an existing registry available to researchers at our institution. This registry guaranteed the credibility of the diagnosis of AS and also provides other demographic and cognitive data.

Participant screening and recruitment proceeded in two stages. First, study coordinators with clinical expertise selected families to contact from the registry. Inclusion criteria for this stage were: 1) child diagnosed with autism; 2) child is between ages of 10-17; 3) child and parent can speak and read English; and 4) child's cognitive abilities are aligned with their chronological age, as measured by cognitive assessment data present in the registry.

Then, study coordinators conducted phone interviews to further screen parents, prior to the initial visit. Additional inclusion criteria for this stage were: 1) confirm that child meets the aforementioned inclusion criteria; 2) child would be comfortable completing study activities, i.e. playing a science game on a computer, watching and discussing clips from a movie, and then answering questions about their experiences via surveys and interviews with the research team.

A total of 39 participants volunteered to participate in this study during the spring and summer of 2019: 25 children on the autism spectrum (AS), 14 typically developing (TD) children, and 20 parents (some parents brought multiple children). 1 participant (AS) was unable to complete any sessions, and 2 participants (AS) only completed one session, and so we report data in this paper for the remaining 36 participants who completed both sessions.

Study Procedures

Next, sessions were scheduled for those participants meeting these inclusion criteria. Participants, including parents and children, received a $50 Amazon gift card for each visit.

Table 1: **Demographics of participant sample.** Some data are missing due to technical issues with our eye tracking and screen recording equipment.

		Autism Spectrum (AS)	Typically Developing (TD)
Full study	N	22	14
	Age (years)[1]	14.0 (2.4)	12.7 (1.8)
	Gender[2]	16 M, 6 F	9 M, 5 F
Subset analyzed for BB performance	N	20	11
	Age (years)[1]	13.9 (2.4)	12.8 (1.8)
	Gender[2]	15 M, 5 F	6 M, 5 F
Subset analyzed for BB gaze	N	12	7
	Age (years)[1]	13.6 (2.4)	12.3 (2.1)
	Gender[2]	9 M, 3 F	4 M, 3 F
Subset analyzed for film gaze	N	5	8
	Age (years)[1]	14.2 (2.6)	13.3 (1.8)
	Gender[2]	4 M, 1 F	3 M, 5 F

[1] Age given as mean (standard deviation). [2] All participants in our sample identified as male or female.

Visit 1 consisted of playing the tutorial module of the science game, Betty's Brain, completing two standardized self-report surveys on social and emotional behaviors and one standardized self-report on the usability of Betty's Brain, and participating in an interview with the researcher to share their experience and feedback on Betty's Brain. The duration of visit 1 was between 60 minutes to 90 minutes. Visit 2 consisted of watching short clips and answering questions about the social content in the clips with the researcher (see Table 2). The duration of visit 2 was between 60 minutes to 90 minutes. Eye tracking data was collected during both visits.

Researcher's Positionality. The researcher who facilitated the Visit 1 and Visit 2 sessions and recorded the observations below holds a Ph.D. in Education, with expertise in qualitative methodology. She has experience working with children and adolescents who have diverse learning needs (e.g., AS, learning disabilities) in non-clinical settings and has conducted research mainly on evidence-based practices aimed at improving students' social and emotional outcomes.

Session 1: Betty's Brain

Betty's Brain is a science education platform that uses a learning-by-teaching approach to help middle school students learn how to represent and reason about complex systems by building causal models (Leelawong & Biswas, 2008).

In particular, students are asked to "teach" a virtual agent Betty (Figure 1, character in top left) about a topic by first reading textbook-like pages about the topic and then building a concept map that is supposed to represent Betty's knowledge (Figure 1, main concept map pane). The concept map consists of nodes, representing concepts from the reading, and edges, representing causal connections among them. To assess how well the students have taught Betty, she periodically takes quizzes that test her knowledge. For each quiz question, Betty's answer is automatically generated based on the state of knowledge represented in her concept map. Finally, another virtual agent Mr. Davis (Figure 1, character in middle left) provides hints to students if they get stuck.

Typically, students complete *Betty's Brain* activities individually or on teams in a classroom setting, over the course of multiple days or weeks. Content modules include various science topics such as ecosystems, human physiology, etc. For our study, we chose an existing, self-contained *Betty's Brain* tutorial module on the topic of forest ecosystems.

The *Betty's Brain* tutorial module is divided into two parts. First, students click through an interactive introduction to the system, including explicit instruction about how to navigate between the textbook view and concept map view, how to take notes from the textbook, how to add nodes and links to the concept map, how to ask Betty to take a quiz, and how to ask Mr. Davis for hints. Then, students transition into an unstructured concept mapping phase, in which they iteratively read the textbook, build their concept map, and quiz Betty, all at their own pace. For context, adult members of our research team and local middle school teachers without any prior experience with the *Betty's Brain* system were able to successfully complete the tutorial in about 30-45 minutes.

Session 2: Social-Reasoning QA

Visit 2 involved much more interaction between the researcher and the participant, in part because of the nature of the activity. Specifically, the researcher started the session by showing the participant a brief clip and then engaged in a guided, yet open-ended conversation with the participant.

The researcher always started the session with the relatively easy film clip: *Cooperation.* The research team categorized this clip as easy due to falling under the genre of animation and the fact that the overall message of the clip,

Table 2: **Television and movie clips from our social-reasoning question answering (QA) activity.** Clips spanned a range of media types and genres, and contained a variety of complex social content across many different scenarios.

Type	Genre	Movie/Show	Scene	Link	Time (min:sec)
Animated	Comedy	Cooperation	n/a (stand-alone)	https://www.youtube.com/watch?v=uL5mHE3H5wE	0:00 - 1:20
Animated	Comedy	Secret Life of Pets	The Best of Chloe	https://www.youtube.com/watch?v=YdroO0omUfg	0:00 - 0:48
Animated	Comedy	Sponge Bob Square Pants	MuscleBob BuffPants	https://www.youtube.com/watch?v=CZ0-3S_LwfA	0:00 - 1:17
Animated	Drama	Dear Alice	n/a (stand-alone)	https://www.youtube.com/watch?v=phQDinMbmic	0:00 - 3:40
Animated	Drama	Big Hero 6	Meet the Team	https://www.youtube.com/watch?v=hv4kPhwHMxA	0:00 - 0:27
Animated	Drama/Fantasy	Soar	n/a (stand-alone)	https://www.youtube.com/watch?v=UUlaseGrkLc	0:00 - 1:30
Live-action	Comedy	Big Bang Theory	Positive Reinforcement	https://www.youtube.com/watch?v=JA96Fba-WHk	0:00 - 1:41
Live-action	Comedy	Big Bang Theory	Sheldon's OCD	https://www.youtube.com/watch?v=caeDFr9MBQg	0:00 - 1:00
Live-action	Comedy	Fresh Prince of Bel-Air	The Carlton Dance	https://www.youtube.com/watch?v=Lxqa2Haf8lo	0:00 - 1:24
Live-action	Comedy	Mean Girls	Lunch Scene	https://www.youtube.com/watch?v=PwKLjeq9j3Q	1:30 - 2:45
Live-action	Comedy	Mrs. Doubtfire	I Do Voices	https://www.youtube.com/watch?v=6wC2DqFJ7UE	0:00 - 1:33
Live-action	Comedy	My Big Fat Greek Weeding	Christos Anesti	https://www.youtube.com/watch?v=FukDxPYDbC8	0:00 - 0:39
Live-action	Drama	Hidden Figures	Car Scene	https://www.youtube.com/watch?v=W1VZ1-ZdQ7k	0:00 - 2:55
Live-action	Drama	My Shoes	n/a (stand-alone)	https://www.youtube.com/watch?v=SolGBZ2f6L0	0:00 - 3:50
Live-action	Drama	Wonder	School Tour Scene	https://www.youtube.com/watch?v=ceWNY5eNSWY	0:00 - 2:23
Live-action	Drama/Fantasy	Harry Potter and the Chamber of Secrets	Breakfast at the Weasley's	https://www.youtube.com/watch?v=ZUl4amon00E	2:09 - 2:44

that is, to help others be safe by working and cooperating together, was exaggerated and repeated through three different scenarios with the penguins, ants, and birds.

After the researcher showed the clip, she asked the participants easy (e.g., "What did the penguins see coming towards them?") to progressively challenging questions (e.g., "What were the ants thinking about the anteater when they saw the anteater coming towards them?"). As participants responded and progressed through these questions, the researcher would move on to more challenging clips and questions, including questions loading on social reasoning and especially ToM.

Results: Researcher Observations

We present results from our study in three categories: general observations by the researcher conducting the sessions, including examples of both positive and challenging engagement across both activities; quantitative performance results from the Betty's Brain educational technology; and quantitative eye tracking results from both activities.

Betty's Brain: Observations of positive engagement

The researcher observed that most participants in both groups appeared to enjoy being able to create relationships between concepts, such as linking rainfall to grass with a positive link in the concept map. A number of participants developed intricate concept maps with a web of causal relationships, though most participants did need guidance to learn how to navigate the user interface and especially the concept mapping page.

Many participants took their time playing the game and, when the researcher checked in after 30 minutes, several did not want to stop! In fact, many participants appeared to demonstrate persistence and motivation, in that they wanted Betty to literally grow "smarter" as a result of their efforts.

Betty's Brain: Observations of challenges

The research observed that, on the flip side, several participants in both groups did grow frustrated while playing Betty's Brain, especially when, despite their concept mapping efforts, Betty earned poor scores on the automatic quizzes. Frustration seemed to stem both from a lack of feedback from the system as to how to improve their concept maps, as well as, for some participants, a strong desire to see Betty achieve a "perfect" score. (Of note: Feedback is a feature of the full Betty's Brain system, though not the tutorial version we used for this study.)

On a related note, even when participants understood how to navigate the concept mapping interface, many seemed to find the process of hovering, clicking, and deleting to be cumbersome and perhaps obsolete, especially in comparison to the flashier, newer commercial games that they are likely exposed to at school or at home.

Betty's Brain: Observations of group differences

The researcher observed that most TD participants spent more time reading the instructional text before engaging in the mapping activities. (This was borne out in our quantitative data; see Figure 2.) As such, they appeared to have a more accurate understanding of the objective of the game.

In contrast, many (though not all) AS participants largely skipped reading the instructional text and scientific content. Indeed, there was a substantive amount of text that participants needed to read in order to successfully understand the material and construct their concept maps. It appeared that reading comprehension and digesting a large amount of material (e.g., a few paragraphs) challenged our AS participants more so than our TD participants.

Consequently, many of the AS participants eventually became disinterested, and the researcher observed the following examples of disinterest: looking away from the screen; staring at the screen for an extended period of time; and requesting to stop the game altogether. Several AS participants did not understand the actual objective of the game and, even when provided with clarification from the researcher, did not seem to fully grasp the idea of making causal relationships, nor the high-level task that they were given to perform.

Film Clips: Observations of positive engagement

The researcher observed that many (though not all) participants expressed not wanting to stop the activity, even when the researcher asked if the participant wanted to take a break. Indeed, most participants often laughed when watching the more comical clips, such as the "Carlton Dance" from The Fresh Prince of Bel Air. Numerous participants who had not watched certain movies from which clips were drawn then expressed: "I should watch that movie when I get home!" or "Oh, it's done! I want to know what happens next!"

Most participants were also able to provide a general summary of what happened in the clips (i.e., the sequence of events) and successfully engage in a brief conversation about these events with the researcher. When probed by the researcher, all participants could identify the main characters, and most could also describe characters' motives, thoughts, and emotions, though with varying levels of sophistication.

Film Clips: Observations of challenges

In both groups, the researcher observed that, in contrast with younger participants, older participants (15-16 years old) tended to have more advanced language with which to describe characters' emotions. Furthermore, older participants were better able to provide well-thought-out explanations for why a character behaved, thought, or felt the way they did.

Film Clips: Observations of group differences

In contrast to most TD participants, who did not seem to show clear preferences across types of clips, the researcher noticed that many AS participants preferred animated clips (e.g., *Best of Chloe* and *SpongeBob*) more than the live-action clips (e.g., *Hidden Figures*). In comparison to the TD group, many AS participants experienced greater difficulty in comprehending the social content and dynamics of relationships in the realistic clips. This preference/facility with animated clips could be related to the slower-paced and more visually exaggerated social cues and interactions they contain, in contrast to the realistic and often fast-paced interactions in the live-action clips. This preference could also be due to an affinity for animals, which many of the animated clips featured.

Several participants in the AS sample could recall moments in clips that provided evidence for why a character felt or behaved a certain way, although they could not always explain what that moment meant in their own words. That is, more participants in the AS sample, compared to the TD sample, recited exactly what a character said, but were less able to explain the meaning behind a character's statement, even when explicitly probed by the researcher.

Several times, the researcher noticed that a participant with AS struggled to express what a character felt, or why they felt that way, and gestured or stuttered quite a bit. If this happened, the researcher did not play a progressively more challenging clip. Some AS participants' attention spans also appeared to be taxed after watching six clips–regardless of the genre—and a few AS participants asked to stop the activity.

Results: Student Performance on *Betty's Brain*

Here, we present results from performance on Betty's Brain. Data collected from screen recordings includes:

1. Time spent on the introductory part of the tutorial, during which Betty and Mr. Davis explain the activity and the interface to the user.
2. Time spent on the main activity of the tutorial, during which the user builds concept maps and has Betty take quizzes.
3. The number of nodes contained in the largest concept map generated by the user towards the end of the session. (Some participants deleted their entire map at the very end, which is why we searched the last few minutes to find the "last biggest map.")
4. The number of causal links contained in this "last biggest map."
5. The highest quiz score attained during any part of the session.
6. The number of quizzes attempted by Betty. (Students can ask Betty to take a quiz at any time during the mapping activity.)

Visualizations of these six variables for our two groups (AS and TD) are shown in Figure 2.

As described earlier, one of the most noticeable behavioral patterns across groups was that many participants in the AS group sped through the introductory part of the tutorial, as evidenced by the top left plot in Figure 2.

The second row in Figure 2 shows measures of the size and complexity of the concept maps that students made, i.e. number of nodes (left) and causal links (right). Participants in the AS group showed much more variability in the concept maps created, including certain participants making extremely large maps, and others making very tiny ones.

The third row in Figure 2 shows the highest quiz scores attained on the left, and the number of quizzes attempted on the right. Again, in the highest quiz scores attained, we see more variability in the AS group than in the TD group. One AS participant got the highest quiz score seen in the whole study: 100%. Several students in both groups never got quiz scores higher than zero.

Results: Eye Tracking for Both Activities

We used a laptop-based Tobii 4c eye tracker to collect eye tracking data, with a research license allowing us to obtain the raw eye gaze data. In our preliminary analyses reported here, we only look at the temporal patterns in fixations across activities and across groups. Additional analyses, including studying eye gaze as a function of regions of interest (ROIs) on the screen, are underway.

We calculated fixations by using the fixation points output by the Tobii analysis software, and then dividing fixations separated in time by more than 0.015 sec.

We present results for both the durations of fixations exhibited by our participants, as well as by their fixation rates, sampled as the per-second counts of fixations. Figure 3 shows these two variables plotted by group and by activity. The first two activities on the x-axis are for the Betty's Brain introduction and mapping segments; the remaining activities are the various film clips shown to participants in Session 2. Note that not all participants viewed all clips.

In both groups, the largest differences among activities are between Betty's Brain and the film activities. Participants ap-

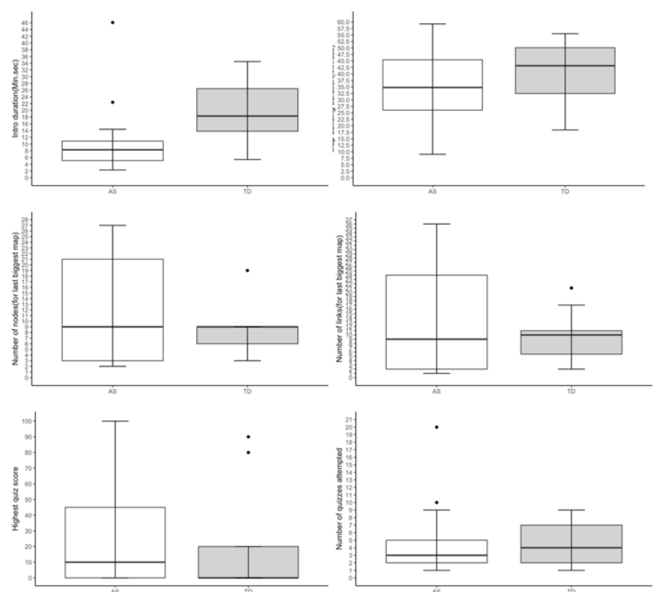

Figure 2: Several behavioral variables extracted from screen recordings of the Betty's Brain tutorial. White bars denote AS group, and grey bars denote TD group. Top row: Time spent on introduction (left), and time spent on mapping activity (right). Middle row: Number of nodes in biggest concept map (left), and number of links (right). Bottom row: Highest quiz score (left), and number of quizzes attempted (right).

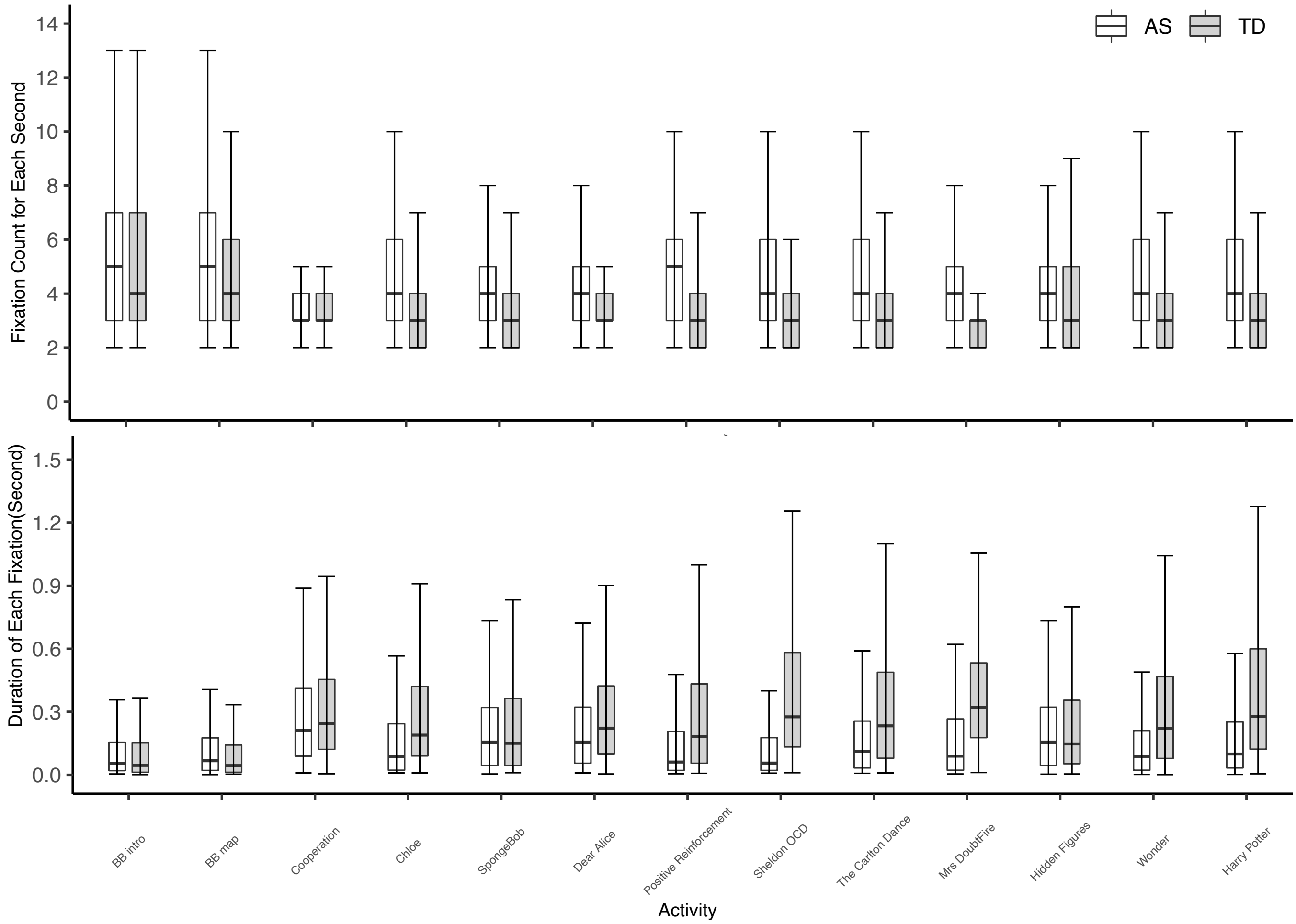

Figure 3: Top: Per-second fixation counts (#/sec) across groups and activities. Bottom: Fixation durations (sec) .

pear to show shorter and more fixations during the Betty's Brain activity. This makes sense, especially as Betty's Brain involves a lot of reading, while the film watching likely includes more sustained foci of attention. Differences among the movie clips seem to be small.

Between groups, AS participants appear to show more frequent, shorter fixations than do participants in the TD group. However, we are currently investigating whether this reflects a true difference in fixation statistics or an artifact of the data processing done to extract fixations (both from the Tobii software and our own processing). It may be that parameters like thresholds need to be set differently across groups, perhaps due to low level differences in eye movement patterns.

Discussion and Future Work

Here, we have presented one multi-modal slice of results from a usability study that we conducted during the formative stages of designing a new, technology-based intervention for helping adolescents on the autism spectrum learn theory of mind and social reasoning skills. Additional results from a parent interview portion of the study have been reported elsewhere (Rashedi et al., 2020), and further analyses of data collected during this study are still underway, including 1) analysis of student interview data; 2) more detailed eye-tracking and usability analysis of the Betty's Brain platform, including quantitative examination of the full system interaction logs and further eye-tracking investigations; 3) more detailed analysis of the film question-answering activity, including qualitative analysis of the students' actual verbal responses during the activity as well as further eye-tracking investigations.

From our observations, we have extracted several recommendations that are pertinent for our own research on developing a new social and ToM intervention for individuals on the autism spectrum. In addition, these recommendations are more generally relevant to the broader educational technology research community on the use and/or adaptation of existing technologies for students on the autism spectrum.

First, we see a need for more deliberately planned instructional phases to introduce students to a new technology. For instance, when instructions come in a form that students can just quickly "click" through, it would help to have additional supports and hints built into the software. Alternatively, additional interactive verification steps could be used to ensure that a student is getting the instructions they need.

Second, frustration seemed to be a commonly occurring reaction, both in relation to perceived usability-related issues with the system as well as when, even if the system was working as expected, the actual gameplay was not going the student's way. Thus, we envision technologies that come with built in "calm down" features. Just as many educational technologies provide hints or other help when students are stuck on a reasoning problem, systems could also provide hints or help when students are "stuck" emotionally. For example, students might select an option that leads them in a 1-minute meditation exercise.

Finally, we were encouraged to observe many elements in both activities that seemed to promote strong engagement: in Betty's Brain, having the characters of Betty and Mr. Davis interact with the user, and embedding the concept mapping activity within a mission to make Betty "smarter;" and in the film activity, allowing students to learn from real television and movie clips that they may already be familiar with.

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