Background Document
Bots in Translation

The goal of the Magical Murder Mystery Tour is to engage second-language learners in a social, immersive, and goal-oriented narrative, thereby motivating them to engage active learning processes. Our approach incorporates a variety of evidence-based principles, including active learning, intelligent tutoring, and social interaction. Our primary motivation was to create a social situation that stimulates curiosity and information sharing, encouraging players to overcome hesitance to use an unfamiliar language and engage in the same curiosity-driven style of learning used by children. Students value teaching methods that use social interaction, believing them to be more effective (Hurst, Wallace, & Nixon, 2013). Language is essential for most social interactions, and language in a community is the entire means of “making meaning” (Vygotsky, 1978). Any group of language learners will have a distribution of comprehension and production ability, and we induce additional knowledge asymmetries by giving each participant a different private history. Learners will thus seek out and interact with more knowledgeable others (MKOs) who have better understanding of either the to-be-learned language or the to-be-solved mystery. Through these goal-directed social interactions, players will find the most useful conversational partners—at their zone of proximal development—and thus naturally scaffold both their language knowledge and understanding of the situation, in line with principles laid out by Vygotsky (1978). The Botfather host, a slack chatbot, also serves as an MKO, offering some language tips as well as useful questions for confused players to ask others. Chatbots have recently seen increasing use as electronic tutors for use in educational settings to facilitate and guide students while learning. However, the difficulty of electronic MKOs, unlike other human learners, is that they must be programmed to have more knowledge than the learner, and to be able to effectively deploy it. Natural, human-like language interactions remain a significant obstacle to the creation of broadly useful intelligent electronic tutoring systems.

In the following, we offer an overview of the diverse research on active learning in cognitive and educational science, which generally shows strong benefits for a variety of active and interactive learning scenarios. Finally, we offer a brief overview of interactive intelligent tutoring systems, which have been found to offer some of the same benefits of 1-on-1 tutoring, the most effective known educational intervention (Bloom, 1984).

Active Learning in Educational Science

“Active” or “self-directed” learning has decades of support and interest from education practitioners and researchers. Teaching that promotes active learning is contrasted with the typical classroom lecture format, wherein students passively listen to academic content. Active learning approaches in the classroom vary greatly—from group problem-solving, worksheets or tutorials completed in class, use of personal response systems in classroom polls, to workshop course designs—and can improve students’ academic outcomes (Kornell & Finn, 2016). A meta-analysis for college STEM courses found that exam scores improved by about 6% in courses with active learning sections, and students in traditional lecturing courses were 1.5 times more likely than active learning students to fail (Freeman et al., 2014).

How does control of the learning process benefit students? Learners can make decisions about time planning, choose specific learning goals and activities, test their own progress, and reflect on errors and successes. They are active in the preparation, execution, regulation, feedback and maintenance of the learning situation. Students who ask questions, for example, may benefit both because they receive answers that are useful, and they make decisions about what questions to ask (Markant, Ruggeri, Gureckis, & Xu, 2016). When learners are “meta-cognitively” engaged, they can optimize how new information builds on prior knowledge and follow their own interests and motivation (van Hout-Wolters et al., 2000).

Educational studies examine the benefits of a variety of active learning practices. One example is the generation effect, which is the finding that information is more likely to be remembered when it was studied under conditions that required the learner to produce some or all of the materials themselves (as opposed to reading what others had prepared; Bertsch & Pesta, 2014). Several researchers have found higher scores for students who only receive a general outline of lecture notes and have to complete the full information themselves, compared to those given a complete set of notes (e.g. Barnett, 2003). Katayama and Crooks (2003) found that students given partial notes to fill in performed better on a test compared to students given full notes, and their scores were more consistent when retested one week later. A similar generation effect was found by Russell, Caris, Harris, and Hendricson (1983) after a 2-to-4 week delay in retest.

Other benefits to active learning are a product of introducing mild difficulties and errors with feedback. Kapur and Bielaczyc (2012) found that students in a productive-failure group, who worked on very complex problems with feedback at the end from the teacher, outscored students in a direct-instruction group. Moreover, students in the productive-failure condition who generated multiple approaches to solve the complex problems showed more benefits than students who did not generate multiple approaches. Feedback has the additional benefit of influencing how much time learners allocate to an activity. Research shows that students devote more time and effort to those tasks for which timely and specific feedback is available (e.g., Northcraft, Schmidt, & Ashford, 2011). The availability and quality of feedback can cue students to the importance of particular content (Hattie & Yates, 2014).

Active learning is a key feature of several successful educational interventions to close income-based achievement gaps. Active learning is linked to self-regulation, which includes but is not limited to attributes such as maintaining attention, regulating emotion and stress response physiology, reflecting on information and experience, and engaging in sustained positive social interactions with teachers and peers (Blair & Raver, 2015). Within the framework of self-regulation, executive functions are higher-order cognitive control skills, such as the ability to inhibit a prepotent response, hold items in working memory, and flexibly shift attention. These skills are manifestly important for success in school. Children from backgrounds of poverty and stress are at risk for poor self-regulation and executive function skills, which contribute to gaps in academic outcomes compared to their high-income peers (Ursache, Blair, & Raver, 2012). These learning gaps emerge in the first years of life, widen in primary school, and shape academic achievement and well-being trajectories into adulthood (Blair & Raver, 2012).

Programs that teach low-income preschool children to engage in active learning through structured play can close income-based gaps in early math and pre-literacy, in part by increasing children's self-regulation and executive function skills (Ursache et al., 2012). For example, the Tools of the Mind preschool curricula emphasizes collaborative scaffolded learning through sociodramatic play, where children cooperatively plan scenarios and act them out according to the rules they had chosen to govern the story and characters (Bodrova & Leong, 2007; Diamond et al, 2007). The promotion of active learning within a developmentally appropriate structure creates conditions of optimal attention and engagement to support children's self-regulation and school readiness (Ursache et al., 2012). Active learning interventions focused on self-regulation have also netted positive benefits at primary and secondary school ages. A recent meta-analysis found these interventions average in effect sizes of over half a standard deviation increase in academic scores, with particularly strong effects for mathematics skills (Dignath & Büttner, 2008). When students with weaker academic skills are taught strategies to learn and think independently and effectively, their learning performance improves dramatically (Palinscar & Brown, 1984; Resnick, 1987).

To summarize, education research finds that students who have control over the rate and content of the learning situation have better academic outcomes. Active learning increases engagement, builds self-regulation skills, and allows each student to tailor the learning situation to match his or her prior knowledge and areas of need. Students benefit from self-generating answers and receiving specific feedback on errors. Active learning with scaffolded feedback is especially helpful to improve outcomes for children with weaker academic skills, or those who come from backgrounds of stress or poverty.

Active Learning in Cognitive Science

Though active learning has a long tradition in educational science, only recently has substantial attention been given to self-directed information acquisition in the cognitive and neuropsychological literatures (Gureckis & Markant, 2012). Basic research is typically designed with an experimenter controlling the flow of information trial by trial. Participants passively receive information without control over content, time duration, or sequence. However, efforts to model human learning have led to a wave of studies exploring how individuals strategize to solve problems. In these studies, learners are in control of what information they experience by way of their ongoing decisions (Gureckis & Markant, 2012). This control can be exerted through physical activity during a task, generating and testing hypotheses, or selectively choosing to attend to different cues or features of the presented stimulus (e.g. Rehder & Hoffman, 2005).

Experimental studies in the areas of category learning and causal inference find that adult learners perform better when given control over what information they want to experience (e.g. Sobel & Kushnir, 2006). For example, Castro et al. (2008) found that allowing learners to actively select training examples greatly improved the efficiency with which they learned a category boundary. Markant and Gureckis (2010; 2012) allowed learners to design examples of objects that they would like to learn about, in order to correctly identify the features of unknown categories. For example, if two categories differed by size, participants could query the category membership of a continuum of different sized objects to find the boundary between “small” and “large.” When learning novel perceptual categories, participants who were free to query individual examples in a self-paced way outperformed participants who viewed examples that were randomly generated (Markant & Gureckis, 2010). Analysis of the self-directed participants’ learning patterns suggested that active learners avoided redundant examples that they could already classify, thus optimizing the learning situation to fill in personalized gaps in knowledge.

Research also shows that active learning is superior to passive learning in diverse tasks such as spatial recall and cross-situational word learning. In spatial tasks, active participation may be only physically controlling movement through a real or virtual environment. For example, participants who walk through a series of hallways typically have better memory for the route as compared to those who are passively conveyed along the same path in a wheelchair (Chrastil & Warren, 2012). Similarly, actively manipulating objects on a display led to faster recognition during a subsequent test than viewing videos of the same interactions (Harman et al., 1999). In a word learning task, Kachergis, Yu, and Shiffrin (2013) found that adults who were able choose which objects they would like to hear named on each trial outperformed those who passively listened to object naming. Active learners who used the strategy of requesting immediate repetition of multiple word pairs performed the best. Moreover, adults who completed the active learning condition first were better at subsequent passive learning, suggesting that some part of their active information strategy carried over.

Are people also able to optimize learning strategies when given control over information flow? Sim, Tanner, Alpert, and Xu (2015) found that children had the capacity to engage in and benefit from active learning. They demonstrated that children were capable of learning categories from self-directed information sampling, could sample in a systematic manner, and learned more from active sampling than when passively presented with a random sequence of examples. Ruggeri and colleagues found that control over study in a memory card game led to improved recall for studied items among 6-8-year-old children, and this advantage remained in a follow-up recognition test after a one week delay (Ruggeri, Markant, Gureckis, & Xu, 2016). The benefits of active learning can been found at even preschool ages. For example, Partridge, McGovern, Yung, and Kidd (2015) found that children had better memory for novel word-object associations when they chose which objects to learn about during study, as compared to passive observation.

The idea of both children and adults as active participants in their cognitive development has been reinforced since the days of Piaget and Vygotsky. Piaget (1930) believed that people come to understand causal relationships through active exploration of their environment, and build knowledge rather than copying or passively receiving information about the world (Schulz & Bonawitz, 2007). Developmental scientists substantially agree that children acquire new information through play (e.g. Bruner, Jolly, Sylva, 1976; Singer, Golinkoff, & Hirsh-Pasek, 2006). This play can resemble hypothesis testing. For example, Schulz and Bonawitz (2007) found that preschool children play more with a toy after being shown confounded information about how it works, suggesting that exploratory play may help to reduce uncertainty about causal structure. Children can actively employ the “scientific method” through play by meaningfully creating, testing, and updating beliefs about how the world works.

In sum, cognitive science literature finds that both adults and children perform better in a wide variety of learning and memory tasks when given active control over the flow of information. This control can be physical, such as walking through a space or touching objects, or involve cognitive processes such as deciding which individual items to ask about during a learning problem. Complementing the broader active learning perspective of the educational literature, cognitive science experiments can delineate real-time, neuropsychological mechanisms that support learning under conditions of active control.

Interactive Tutoring Systems

Millis, Graesser, and Halpern (2014) created an interactive tutoring system, Operation ARA, that featured animated teacher and student agents that teach scientific inquiry and research evaluation skills to high school and college students. The design, structured around a storyline and game, featured 3-way tutorial interactions that prompted the student to ask questions about content with interactive feedback from the agents. Based on more than 20 studies, the authors report an average effect size of .80 (Graesser et al., 2012), which corresponds to a full letter grade in the United States.

Several meta-analyses have evaluated the role of interactive games in educational programs (e.g. Wouters, van Nimwegen, van Oostendorp, & van der Spek, 2013). For example, Vogel et al. (2006) investigated both cognitive and attitudinal effects of game-based learning and found that computer games and interactive simulations yielded higher cognitive outcomes than conventional learning methods. Educational games are also a promising area for intervention in developing countries. For example, Pratham and the Azim Premji Foundation have used computer game initiatives for children in the urban slums and rural areas of India. A large-scale intervention by Pratham found significant gains on mathematics test scores from playing computer games that target math learning (Banerjee, Cole, Duflo, & Lindon, 2005).

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