Running Head: THE MOTIVATIONAL TOOLS OF EXPERTS

Motivating persistence in the face of failure:

Equipping novice learners with the motivational tools of experts

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Throughout their school careers, students encounter many challenging learning tasks where some degree of failure is inevitable. When doing a math problem, coming up with an idea for an essay, or writing a computer program, students' first attempts may fail. Often times, students take the easy way out by giving up on the task entirely, which impedes learning. Ideally, students will persevere through these failures, learn from their mistakes, and eventually master the relevant concepts and skills. But rebounding from failure requires a sophisticated set of motivational behaviors that many novices, including children, often do not perform.

How can we foster student persistence in the face of failure during learning? In this chapter, I look to experts as models of tireless persistence in the face of failure. Presumably, this persistence has aided them in learning their domain of expertise and has eventually led them to become successful at what they do. In the research presented here, I examine the motivational tools that experts employ in the face of failure with an eye towards supplying them to novice learners. I then discuss a technology-based classroom intervention called Teachable Agents, which, I argue, provides novice students with the motivational tools of experts, enabling them to persist after failure and learn from challenging tasks.

Expert persistence in the face of failure

Experts have knowledge, skills, and mental representations that far surpass those of novices or even skilled practitioners. How do experts come to possess these superior cognitions and skills? When asked this question at a conference, Bill Chase responded with the adage "no pain, no gain." Experts get good at what they do through plain hard work. Indeed, the expert chess players that Chase studied had practiced approximately 10,000 hours before gaining international-level playing skills (Chase & Simon, 1973). Several studies have now shown that it takes ten or more years to become an expert across many domains such as music, medicine, and mathematics (Ericsson & Lehmann, 1996).

But not everyone becomes an expert after 10,000 hours of practice. True experts undertake “deliberate practice,” where they systematically rehearse a particular skill (Ericsson, Krampe, & Clemens, 1993). For instance, chess players will re-enact famous games and attempt to predict their moves, and musicians will sustain hours of solitary practice on a single piece. While practicing deliberately, experts maintain intense levels of concentration and effort even though they often find it unpleasant (Ericsson, Krampe, & Clemens, 1993). In fact, many experts are unable to sustain deliberate practice for more than four hours a day because it requires such extreme physical and/or mental exertion (Ericsson, 2002).

During deliberate practice, experts push themselves to attempt challenges beyond their current level of ability. Bereiter and Scardamalia (1992) call this “progressive problem-solving,” where individuals “work at the edge of their competence” by giving themselves progressively more difficult challenges. They studied expert writers who generated demanding writing problems for themselves. These problems pushed the experts to discover new knowledge and new styles of writing (Scardamalia & Bereiter, 1987).

But when experts work at the boundary of their abilities, attempting extremely difficult tasks, they are bound to experience failure. Even Michael Jordan, a basketball legend, has failed many times, as illustrated by this quote from a television commercial: “I've missed more than 9000 shots in my career. I've lost almost 300 games. 26 times, I've been trusted to take the game winning shot and missed. I've failed over and over and over again in my life. And that is why I succeed.” If experts frequently work on tasks they have not yet mastered, failure along the way is inevitable.

But failures can lead to learning. John Dewey once wrote, "Failure… is instructive. The person who really thinks learns quite as much from his failures as from his successes" (Dewey, 1933/1998, p. 142). The discrepancy between intended and actual outcomes provides information that fuels analysis (Wiener, 1948). New discoveries are often made when experiments come out differently than predicted. In a study of a molecular biology lab, Dunbar (1999) found that biologists paid particular attention to discrepant results. Asking why these results had occurred often pushed them to generate novel theories and innovations in their field. The same principle applies for children learning in school. For instance "struggling and making mistakes are believed to be essential parts of the learning process in Japan," where teachers let students make errors and learn from observing their consequences (Stigler & Hiebert, 1999, p. 91). So too experts must learn a great deal from failing at challenging tasks and then working through their mistakes.

But failure can be debilitating. Studies have linked the experience of repeated failure to low self-efficacy, learned helplessness, and even depression, conditions that strongly hinder motivation (Bandura, 1997; Peterson, Maier, & Seligman, 1993). Yet somehow, experts find ways to persist after failure, and presumably, these failures help them become the best at what they do. But exactly how do experts sustain the motivation to persevere in the face of constant failure?

In the remainder of this chapter I will address this question, with an eye towards designing interventions to help novices persist during challenging learning tasks. I begin with a summary of motivational theories that could explain experts' motivation in the face of failure, highlighting where they are relevant to an intervention for novices. I then describe a suite of motivational tools – an ego-protective buffer, acceptance of responsibility, and an actionable path – that appear to help experts persist and learn in the face of failure. A study of expert motivation presents suggestive evidence for these tools. I then go on to describe a computer-based intervention called Teachable Agents, where students learn by teaching a computer character. Finally, two studies suggest that the Teachable Agent software leads children to adopt the motivational tools of experts, persist at difficult learning tasks, and make significant learning gains.

What motivates experts?

What motivates experts to persist for thousands of hours of deliberate practice, enduring frequent failure? Unfortunately, there is very little research on the motivation of experts, but there are two motivational constructs that seem intuitively applicable: self-efficacy and intrinsic motivation.

Self-efficacy is the belief that one is capable of performing a specific task. According to Bandura (1997), the most robust source of self-efficacy is accumulated past experiences of success with a particular task. Most experts are differentiated from novices and mere skilled individuals by their ability to perform extremely well in evaluative contexts like competitions, academic tests, or public presentations. So while experts often fail during deliberate practice, they experience a great deal of success in performance venues. These experiences of success lead experts to cultivate a strong sense of self-efficacy for tasks in their domain.

Bandura (1997) hypothesizes that high self-efficacy for a particular task leads individuals to persist in the face of difficulty, attribute failure to external or unstable causes, and rebound quickly from failure, because they believe that they can succeed (Kitsantas & Zimmerman, 2002; Silver, Mitchell, & Gist, 1995). A lack of this belief, demonstrated by low self-efficacy, leads individuals to persist for shorter periods of time, attribute failure to internal or stable causes, and give up after failure. According to Bandura, a well-developed sense of self-efficacy is important for generating a healthy response to failure.

There is some evidence that experts have high self-efficacy for tasks in their domain. In a study of expert, non-expert, and novice volleyball players, the experts rated their self-efficacy significantly higher than both non-experts and novices before executing a serve (Kitsantas & Zimmerman, 2002). Moreover, their self-efficacy rating did not change after missing a serve, while the self-efficacy rating of both non-experts and novices declined after failure. This stable sense of self-efficacy could help experts endure extended periods of failure during training.

Another obvious motivator for experts is their intense passion for their domain. If experts are willing to practice for thousands of hours, then they probably like what they do. That means experts almost certainly have a well-developed personal interest (Renninger, Hidi, & Krapp, 1992) and are intrinsically motivated in their area of expertise (Deci & Ryan, 1985). In the same study of volleyball players described above, experts rated their intrinsic interest in the overhand serve significantly higher than both non-experts and novices (Kitsantas & Zimmerman, 2002). Intrinsic motivation has been shown to predict people's choice in activities and how long they are willing to persist at those activities (Deci & Ryan, 1985). It seems likely that a strong interest in their topic of expertise could spur experts to initiate deliberate practice and persist when they encounter obstacles in their domain.

From Experience Driven Motivations to Motivational Tools

When considering how to help novices persist after failure, it seems ill-advised to rely directly on the motivational constructs of self-efficacy and domain-specific intrinsic motivations, at least early on. With little knowledge and experience in a domain, novices cannot have attained the success necessary for high self-efficacy in domain-specific tasks, nor can they have the deep intrinsic motivations that drive experts to engage tasks at their "breaking point." Given the limitations of self-efficacy and interest for sustaining novices' persistence in the face of failure, a search for more practical, intervention-focused motivators is warranted. A study with experts suggested a confluence of three motivational tools that yield persistence after failure: an ego-protective buffer, acceptance of responsibility, and actionable paths for making progress. I describe the motivational tools first, and then describe the relevant study.

A motivational tool supports and encourages motivation in a specific context; in this case, the context is failure. Like cognitive tools and physical tools, these motivational tools can be used and possessed by people, though not necessarily deliberately. Motivational tools differ from more general motivational constructs like self-efficacy or intrinsic interest, which rely on developed self-concepts and preferences. Motivational tools can be more easily manipulated. So while it can be difficult to increase student self-efficacy or sustain intrinsic interest in the face of failure, we can provide students with motivational tools. Another benefit of motivational tools is that they suggest specific design points for interventions, which I describe in a subsequent section.

An Ego-Protective Buffer

An *ego-protective buffer* lessens the impact of failure on one's psyche. Chemical buffers are substances that maintain a stable pH in a solution by neutralizing the effects of added acids or bases. An ego-protective buffer maintains a stable sense of competence by allowing the learner to place some of the blame for failure on an external agent like the situation or the difficulty of the task. This protects the learner from self-blame and its accompanying assumption – that the learner has poor ability or low intelligence.

The ego-protective buffer relates to attribution theory, which claims that individuals are motivated to find the causes of significant outcomes like failure so they can determine how to avoid failure in the future. One dimension of attributions is their locus; attributions can be internal or external to the individual. Attributing failure to some internal causes, like fixed ability or intelligence, can have a negative impact on expectations of future success, persistence and even performance (Anderson & Jennings, 1980; Weiner, 1985), whereas attributing failure to external causes can boost self-esteem (Weiner, 1979). By enabling attributions to external causes, the ego-protective buffer blocks unhealthy internal attributions and negative self-thoughts like "I simply don't have the ability to do this" or "I'm stupid."

This is important because negative self-thoughts pull cognitive resources away from the task at hand, making learning much less likely to occur. For instance, individuals with test anxiety often have a solid understanding of the concepts but simply do not perform well on tests. This is because during the test, they focus all their cognitive resources on the negative consequences of performing poorly (Wine, 1971). The ego-protective buffer can draw learners away from these negative self-thoughts so they can focus on the learning task.

Acceptance of Responsibility

Simply shielding learners from the negative self-thoughts inspired by failure may not be enough. Learners need to be motivated to do something about the failure, and not simply feel safe from it. Persistent learners *accept responsibility* for repairing the failure and preventing it from occurring again. This sense of responsibility implies that the learner cares about the task outcome. If one feels responsible, then one exercises a sense of ownership and investment in the task and feels a duty to succeed. For persistence to occur, learners must believe that the onus to remedy the failure is on the self, and they must believe that they themselves can control future progress in the task. If learners deem that fixing and preventing the failure is beyond their control, then they will not be motivated to take personal action. This belief can lead the learner to give up on the task, which curtails learning.

This relates to another dimension of attributions – controllability. Controllability refers to whether the individual has the power to change the source of the outcome. Failure due to bad luck is not controllable while failure due to poor effort is the kind of failure that the learner can take action to avoid. In fact, many attribution researchers advocate training students to attribute failure to effort because it boosts persistence (Schunk, 1982; Weiner, 1979). However, I argue that learners can make an external attribution for past performance while taking control over future failures. By accepting responsibility for remedying the failure or preventing it in the future, learners are exercising control over future failures even if they view past failures as dependent on external causes.

So the ego-protective buffer and acceptance of responsibility constructs do not contradict one another. The key distinction is that one can accept responsibility for the future action of remedying the situation without harping on the shame of a past failure. For example, after receiving negative reviews on a submitted journal article, an author might blame the idiosyncratic nature of the reviewers or the writing styles of the co-authors, but in the end, that author will often take personal responsibility for revising and resubmitting the paper. Likewise, experts are highly attuned to the external conditions that affect their performance, and they adapt their behaviors to deal with them (Ericsson, 2002). For instance, when a gust of wind blows a tennis player’s serve out of the court, the player might chalk it up to bad luck. However, he might also believe that if he had aimed more conservatively, the ball would have stayed in. So he might conclude that the failure was caused by bad luck, but he can avoid misses in the future by playing more conservatively on windy days. There are many situations where people blame external sources for failure but take matters into their own hands when it comes to repairing or preventing future failures.

An Actionable Path

Buffering the psyche and intending to fix things may not be sufficient to pull the learner forward. Without a clear *actionable path* for moving forward, the learner can get stuck with no way of moving beyond the failure. Persistence is far more likely if the learner has a store of content-specific strategies or domain-specific knowledge that can be used to develop a new approach to the task. These new approaches are actionable if, in the mind of the learner, they create a potential avenue towards progress. If learners cannot find any actionable paths to take, then they are likely to quit the task, which inhibits learning.

While theories of self-regulated learning recognize that cognitive and motivational concepts are co-mingled (Boekarts, 1997; Pintrich & De Groot, 1990; Zimmerman, 2002), the concept of an actionable path is often overlooked in motivational theory. For instance, many attribution retraining studies teach learners to attribute failure to poor effort or ineffective strategies (Dweck, 1975; Anderson & Jennings, 1980). However, if students have no knowledge of other strategies or no direction for their efforts, this would be a futile approach. Merely trying harder, without knowing what to try, makes it difficult to persist. Interventions aimed at supporting student persistence need to focus on developing students' cognitive resources as well as their motivational ones.

One example of how these three components can come together to motivate persistence after failure is in how teachers are taught to reprimand children by first criticizing the behavior, not the child, and then explaining how the child can change her behavior. For instance, a teacher might start by saying "It's not *you* that I don't like, it's your *behavior*" making clear that the teacher does not have a personal dislike of the child, but rather the behavior is to blame. Then, the teacher might go on to say "Interrupting while others are speaking slows down the class conversation and frustrates everyone. Next time that you're bursting to say something, please write it down so you won't forget, then wait your turn to be called on." Here the teacher clearly places the burden of fixing the behavior on the student. Moreover, she explains a specific strategy the child can use to change her own behavior. Through a combination of these three mechanisms: (1) deflecting the blame away from the student while (2) assigning them personal responsibility for improvement and (3) providing specific strategies for moving forward, the teacher equips her student with an excellent set of tools for persisting after a behavioral failure.

How do experts sustain motivation after failure?

This chapter discusses two specific hypotheses. (1) Experts use a suite of motivational tools – an ego-protective buffer, acceptance of responsibility, and actionable paths – to help them move beyond failure. (2) If we provide these tools to novice students, they should be more likely to persist in the face of failure. I do not attempt to claim that these three tools are either necessary or sufficient for motivating persistence in the face of failure; the studies I present were not specifically designed to test this claim. However, I present suggestive evidence that these tools work effectively in concert.

These three motivational tools emerged from a study on expert motivation that was designed to test whether the motivations that help experts persist in the face of failure are confined to their areas of expertise. I contrasted relative experts in math and English as they performed extremely difficult math and English tasks. This cross-over design was created to compare the motivational behaviors of experts in two different domains: a domain where they are novices and a domain where they are experts. Verbal protocol data were carefully coded for attributions to failure and were also informally analyzed to determine how experts made progress in the tasks. Two measures of persistence were collected – time on task and whether participants chose to revisit the tasks in their spare time.

Study participants were 19 relative experts in either English (n = 9) or math (n = 10); they were upper-level undergraduate students and doctoral students pursuing degrees in either subject. During the study, all experts attempted two tasks – one in math and one in English. For the math task, participants were asked to do a proof involving prime numbers; for the English task, participants were expected to interpret a poem with very oblique language (see Appendix). The tasks were chosen for both their approachability and difficulty, to ensure that while everyone could attempt each task, they were likely to fail.

Participants were told they would have up to 12 minutes to work on each task but they could quit before the time was up, if they wanted. During the tasks, participants thought aloud and their voices were audio recorded. At the end of the session, participants were asked to return a few days later for a brief interview and were informed they would not have to work on the tasks again. However, during the second session, participants were indeed asked to revisit the tasks and think aloud again. This was done to determine whether subjects had chosen to work on the tasks in their spare time, outside the demands of the experiment. During their second attempt at the task, participants often stated whether they had worked on the task in between the two sessions or not. This was confirmed by a brief interview given afterwards.

Figure 1 shows that experts in both math and English spent significantly more time on the task in their domain, using almost the full 12 minutes[1]. Moreover, far more of the experts

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[1]Persistence times were entered into a repeated-measures ANOVA with one between-subjects factor of Expert Type (Math or English) and one within-subjects factor of Task Type (Math or English). Neither main effect was

reported working on the task in their domain during the time between the two experimental sessions[2]. Of the math experts, 100% of them chose to work on the math task while only 30% worked on the English task. The English experts behaved similarly; while 56% of them revisited the English task, only 33% of them returned to the math task. So for tasks in their domain, the experts continued to persist even outside the demands of the experiment, in their free time.

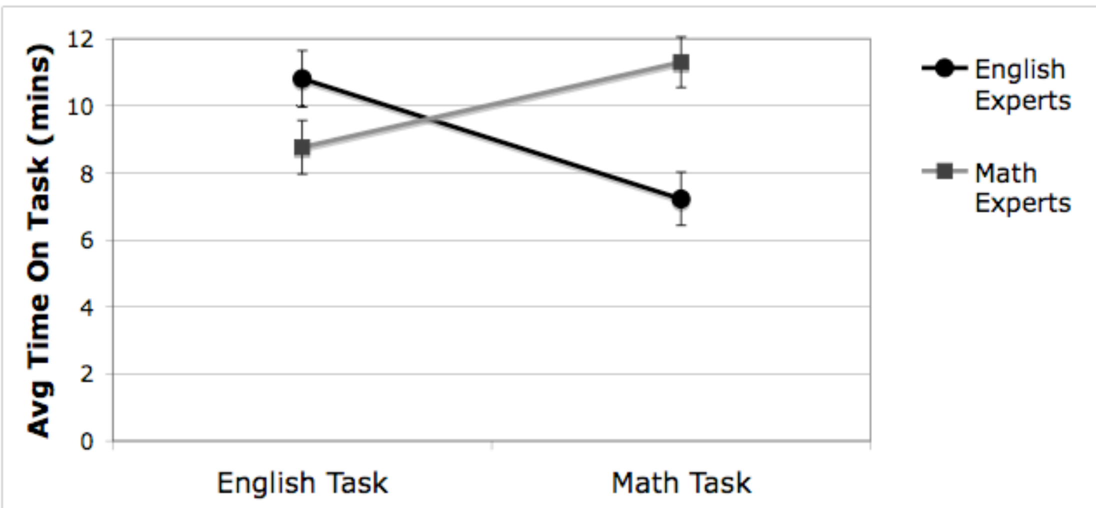

Figure 1. Persistence times broken out by task type and expert type. Experts were given a maximum of 12 minutes to work on each task but were given the option of stopping before the full time. Experts in both math and English persisted longer at the task in their domain of expertise.

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statistically significant, $F_{Expert\ Type}(1, 17) = 1.08$, $p = .31$, $F_{Task}(1, 17) = 0.90$, $p = .36$. However, there was a strong interaction effect of Expert Type by Task Type, $F(1, 17) = 30.34$, $p < .001$. This crossover effect, displayed in Figure 1, shows that math experts persisted longer at the math task, while English experts persisted longer at the English task.

[2] A loglinear model was fit to the three crossed-factors of Expert Type (math or English), Task Type (math or English), and Persistence Choice (yes or no). In the final fitted model, only the three-way interaction was significant, χ^2 $(1, N = 38) = 11.77$, $p < .001$, none of two-way interactions or main effects were significant. The percentage of subjects who chose to persist at each activity in their spare time demonstrates this interaction clearly. Experts were more likely to revisit the task in their domain of expertise.

Hints at why the experts persisted in their domains came from the verbal protocol data. Experts tended to make more external attributions for failure while working on the task in their domain while they made slightly more internal attributions during the task outside of their domain[3]. Figure 2 displays this pattern along with sample attributions. For instance, English experts often blamed the task ("This poem is all over the place – there is no way of connecting these ideas."), the situation ("It's weird to work on it in isolation. If I were doing the task outside of an experiment, there are people I would call, things I would Google."), or sometimes the method ("I need to try other things, try a different approach."), for their failure in interpreting the poem. However, when working on the math problem, English experts often blamed themselves, claiming either poor ability ("I'm not very good at things like this.") or lack of knowledge ("If I knew more algebra, I'd be able to work it out. It's too complicated for my lame high school math."). Though the crossover effect was slightly less prominent in the Math experts (particularly on the English task), overall, Math experts displayed a similar pattern of attributions, citing mostly external causes for failure on the math task ("This is a complicated theorem," "Talking out loud is really slowing me down and screwing me up," "This strategy's obviously not working very well") and slightly more internal causes for the English failure ("This is kind of over my head," "It seems very far removed from anything I have any idea

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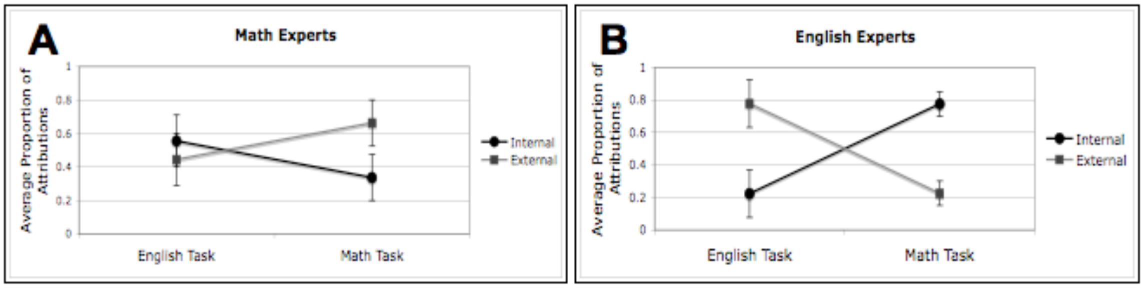
[3] A "locus" score was computed for each subject's attributions during each task by subtracting the total number of internal attributions from the total number of external attributions and then dividing by the total number of attributions made during the task. A positive score indicates a bias towards external attribution, while a negative score suggests an internal bias. The locus score became the dependent measure in a repeated-measures ANOVA with Expert Type (math or English) as a between-subjects factor and Task Type (math or English) as a within-subjects factor. The main effects of Expert Type, $F(1, 15) = 0.19$, $p = 0.67$, and Task Type, $F(1, 15) = 2.50$, $p = 0.14$, were not significant. However, a significant two-way interaction, $F(1, 15) = 6.07$, $p = 0.03$ indicated that both types of experts made more external attributions during the in-domain task and more internal attributions during the out-domain task. Two subjects were dropped from this analysis because they only made attributions during one of the tasks. However the attributions they did make followed the same pattern as the other subjects. For the sake of simplicity, Figure 2 depicts the average proportion of internal and external attributions made by math and English experts during each type of task (rather than the locus score which is more difficult to interpret).

about"). This ability to divert the blame for failure away from themselves and towards external sources is an ego-protective buffer that protects experts' sense of competence in their domain.



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	English Task	Math Task
English Experts	*"This is like vomit on a page. The author provides no hooks for the reader."* *"The author is kind of self-indulgent."* *"I just need more time."*	*"I've never been good at math."* *"Ever since I was 13, I was horrible at math class."* *"I don't know the formal way people would express the proof."*
Math Experts	*"I'm not a literature person."* *"I took a poetry class once and wasn't very good at it."* *"I didn't know all the cultural references."*	*"It's hard to do this while talking out loud."* *"This is an evil math problem."* *"That strategy didn't work."*

Figure 2. Internal and external attributions. (A) Average proportion of internal and external attributions for math experts. (B) Average proportion of internal and external attributions for English experts. (C) Sample attributions. Experts in both areas made more *external* attributions for failure during the *in-domain* task and more *internal* attributions during the *out-domain* task.

At the same time, experts accepted responsibility for repairing the failure. After making mistakes, the experts continued to take productive actions in the task, and they even initiated work on the tasks in their free time, outside the demands of the expert. In contrast, when doing the out-domain task, in which participants were novices, they often stopped taking actions after a few failures and eventually gave up on the task entirely.

Further evidence of experts' acceptance of responsibility comes from the finding that not all of the experts' attributions for the task in their domain were external. About 30% of them were internal. While external attributions allowed experts to protect their egos, the few internal attributions they did make shows that they held themselves accountable for remedying the situation. This is notable since most studies of attribution theory ask participants to select a single attribution for an outcome, when in reality, the participant may subscribe to several different attributions at once.

It is also interesting to note that experts later went on to alter the external causes of their failure by changing the conditions under which the task (in their domain) was performed. During the first session, many of the experts complained about these conditions, stating that they did not have enough time, found it difficult to talk aloud and think at the same time, or did not have access to resources. But by revisiting the task outside the demands of the experiment, the experts eliminated the time limit and the requirement of talking aloud. Many of the experts reported consulting other resources like the Internet or a knowledgeable friend. So the experts were motivated enough to change the external conditions they believed were contributing to the failure, thereby turning uncontrollable external causes into internally controllable ones.

Moreover, the experts had actionable paths for making progress in the task. It was clear from the protocol that both types of experts made significantly more progress on the tasks in their domains. They did so by using specific knowledge and strategies that moved them closer to their ultimate goal of completing the task[4]. For instance, while interpreting the poem, English experts looked for patterns in the punctuation style, analyzed when and why the prose switched voice, and searched for clues to the context in which the poem was written. These methods for analyzing a poem come from experience and knowledge – something that the novice math experts did not have when approaching the poem. The math experts tended to apply very few

[4] Given the high prior plausibility of this claim and the enormous literature that confirms it (Bédard & Chi, 1992; Ericsson & Charness, 1994; Ertmer & Newby, 1996), I chose not to code and count episodes of task progress and their accompanying strategies and actionable paths.

specific strategies or essential information during work on the poem. However, during the math problem, math experts applied several pieces of knowledge about the distribution of prime numbers, the format of proofs, and logical assumptions towards solving it, which the English experts did not. So, both kinds of experts had strategies and knowledge that gave them further avenues to pursue when their first attempts at the task in their domain failed. Whereas, when working on tasks outside their domain, acting as novices, participants quit when they ran out of things to try, saying things like "I'm not making any more progress here. That's all I can do." Participants simply had more actionable paths available to them in their domain of expertise.

This study presents suggestive evidence that experts employ all three motivational tools in the face of failure – an ego-protective buffer, acceptance of responsibility, and actionable paths. While more direct evidence for this claim is warranted before stronger assertions can be made, my interpretation is as follows. Experts are able to divert the negative impact of failure towards external sources while still taking personal responsibility to move beyond the failure, and they do so by implementing practical strategies and useful knowledge that help them progress in the task.

Notice that experts' failure-coping mechanisms are domain-specific; the motivational behaviors that math experts displayed during the math task did not appear when they worked on the English task, and vice versa for the English experts. This provides evidence to refute the claim that experts possess some general trait-like characteristic of high motivation that pervades all their behavior (Winner, 2000). Experts are not motivated to do everything; rather their expert-like motivational tools are reserved for their specific area of expertise.

Providing novice students with the tools to move beyond failure

Experts, who have accumulated years of experience in a domain, have tools for moving beyond failure, but can we encourage novices to show the same persistence in the face of failure? Unlike experts, novices have no prior knowledge, no special interest, and no well-developed sense of self-efficacy in a domain. But if given the right motivational tools, novices should be able to persist in the face of failure, just like the experts.

Software learning environments make compelling motivational interventions because of their affordances for scaffolding learning activities. For instance, cognitive tutors provide just-in-time hints during problem-solving. They also demonstrate specific problem-solving methods through worked examples (Koedinger, 2001). Likewise, scientific simulations provide students with the infrastructure for running experiments. They designate exactly which variables can change and encourage students to make their own changes and observe the consequences (De Jong & Van Joolingen, 1998). In this way, software learning environments can provide students with precise methods for moving forward in a task. If an initial simulated experiment fails, students can try manipulating a different variable. If their problem-solving strategy did not work, students can ask the cognitive tutor for a hint. Software learning environments are well-suited to provide the third motivational component for moving beyond failure – a specific actionable path for making progress in the task.

But how can we provide students with an ego-protective buffer and a sense of responsibility? One way is to introduce another social entity – someone who acts on the students' behalf yet behaves independently. For example, coaches, who train their players, feel responsible for a lost game since the players were acting on their teachings. But the coach cannot be held solely responsible for the players' behaviors. The players themselves clearly had some hand in losing the game. Teachers often feel the same way about their students. Because teachers can have a profound effect on the beliefs, thoughts, and actions of their students, they have a duty to do their job well. At the same time, they realize that students have a will of their own and can easily divert from the teacher's prescribed path. A software learning environment that harnesses this particular kind of social situation could inspire a sense of responsibility while providing an ego-protective buffer to absorb some of the blame for failure.

A Teachable Agent (TA) is one such software learning environment. Based on the narrative of teaching and equipped with supports for specific learning activities, the Teachable Agent contains all the tools for moving beyond failure. A Teachable Agent is a graphical character on the computer that children teach, and in the process of teaching, the children learn themselves. As a product of the child's tutelage, the agent is a reflection of the child herself, but as an independent actor, it takes on a life of its own (Chase, Chin, Oppezzo, & Schwartz, 2009). Occupying the unique social space of part self, part other, the agent motivates students to feel partly responsible for its failures, while the agent itself can shoulder some of the blame. In addition, the software has built-in structures and scaffolds to support specific methods or actionable paths for improving performance.

A Teachable Agent called Betty's Brain

Betty's Brain is a type of Teachable Agent software where students learn by teaching a graphical character on the computer (Biswas, Leelawong, Schwartz, Vye, & TAG-V, 2005; Schwartz, Blair, Biswas, Leelawong, & Davis, 2007). Each student creates her own agent by naming and designing its appearance and then populating its "brain" with knowledge. Students teach their agents by building concept maps of nodes connected by qualitative causal links; for example, 'heat production' increases 'body temperature'. Betty was designed to model chain-like mechanisms of cause and effect. For this reason, Betty is ideal for science domains that have long chains of causal relationships, like those found in many areas of biology.

A Teachable Agent (TA) is equipped with an artificial intelligence reasoning engine which enables it to reason about the information it has been taught. For instance, a TA can answer questions. Figure 3 demonstrates Betty's query feature. In response to a question, the TA will respond by successively highlighting each node and link in a causal chain as it reasons through them. This makes the TA's "thinking" visible to the student, who can revise her agent's knowledge by editing its concept map; meanwhile, the student herself learns along the way.

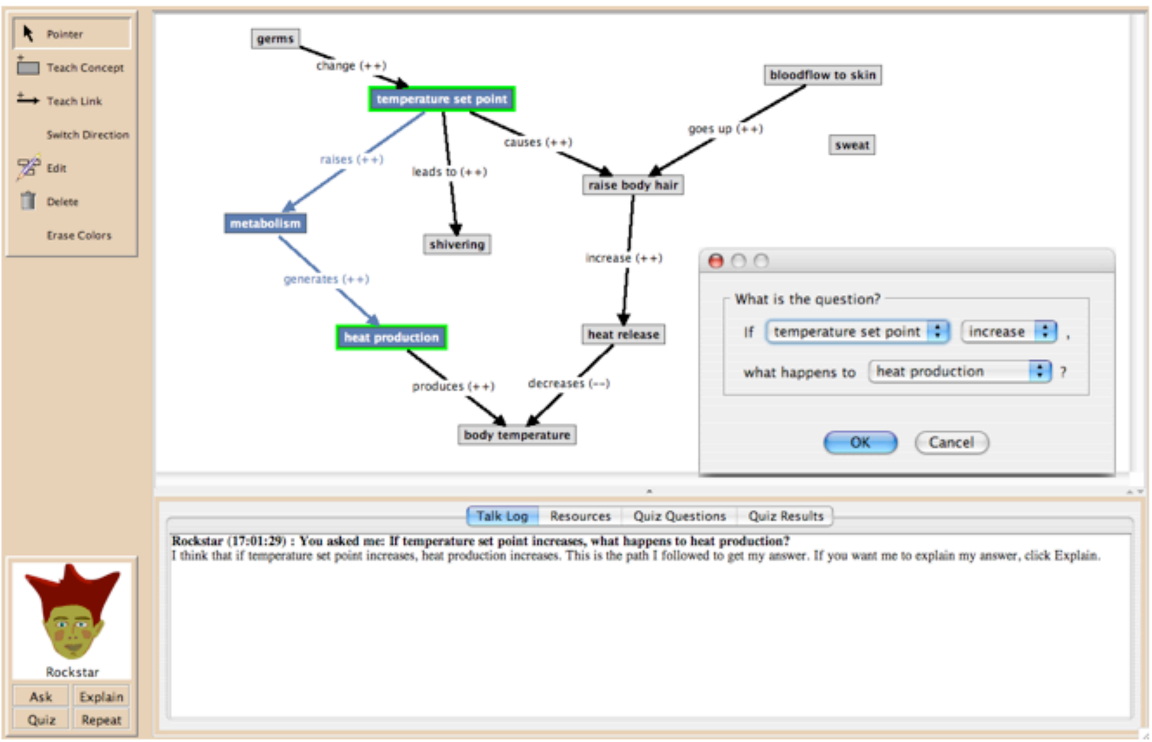

Figure 3. Screenshot of the Betty's Brain interface. In the bottom left corner is Rockstar, a student's agent. A sample student concept map of fever mechanisms is in the center of the frame. In the pop-up to the right of the screen, the student has asked its agent a question about the relationship between 'temperature set point' and 'heat production.' The agent has responded by visually highlighting its reasoning on the concept map and verbally stating its answer in the Talk Log below.

Betty comes with several kinds of feedback features which help students debug their maps and further their understanding of the content. In addition to the query feature discussed above, Betty also contains a quiz feature. When students submit their agents to take a quiz, the TA responds to a set of questions and receives right/wrong feedback, and students can observe the TA's performance. Betty also comes with the Triple-A Game Show displayed in Figure 4 – a Jeopardy-like game where students' agents play against one another. During the game show, the host poses a series of questions. Students wager points on their agent's answer while the host provides right/wrong feedback and awards points. These various features are meant to engage students in the process of teaching while providing feedback on their maps and overall understanding.

Figure 4. Screenshot of the Triple-A Game Show. Agents play against other agents in successively more difficult rounds. During each game, the host poses a series of questions. Students wager on their agent's answers. After all the agents respond, the host tells the correct answer and awards points. During the game, students can chat in the window at the bottom of the screen.

Betty comes with two additional features. One is a chat feature which enables students to carry on a written conversation with one another while working in the Betty software. Another is a set of reading resources that students can access throughout the teaching process, to help clarify their understanding of the concepts.

Past studies have shown that Betty's Brain is an effective learning tool (Schwartz et al., 2009; Chin et al., under review). In one study, 6th-grade students were taught about global warming. In the TA condition, students worked with their TAs to structure what they had learned from various in-class activities and homework. In another condition, students learned the same material, but worked with a commercial concept mapping program called Inspiration. Students took three paper and pencil tests spread out over three weeks of curriculum. Over time, the gap between TA and Inspiration students' test scores widened. Compared to the Inspiration condition, TA students were able to reason about longer and longer causal chains as the unit progressed. These results indicate that Betty's Brain is a valuable classroom learning tool that can help students learn causal relations. The study described next focuses on the motivational benefits of the TA.

TAs seem to contain all the motivational tools for moving beyond failure. The agent can provide an ego-protective buffer – it can act as a scapegoat to take some of the blame. For instance, when a question is answered incorrectly in the game show, students can view it as the TA's fault, not their own. Yet students may still feel responsible for their agent's knowledge. After all, they did program its brain. The TA also provides a specific actionable path for fixing the failure. Correct the links in the agent's map and its performance will improve. Because these motivational elements are built into the TA system, it seems plausible to assume that the TA could help students move beyond failure. A protocol study examining student motivation in the context of the TA offers evidence for this assertion.

Can a Teachable Agent help students move beyond failure?

In this study, twenty-four 5th grade students were pulled from class for individual think-aloud sessions, while they worked with Betty's Brain (Chase, Chin, Oppezzo, & Schwartz, 2009). All students used nearly identical versions of the software that contained an on-screen computerized character. However, one group of students (the TA group) believed they were learning on behalf of their digital pupils while a second group (the Self group) believed they were learning for themselves. Students provided think-alouds while they worked, which were analyzed for evidence of affect and attributions for failure. Persistence times were collected and it was noted whether students chose to revise their agent's (or their own) knowledge following feedback. If the agent provides students with the motivational tools to move beyond failure, then greater persistence and choice of revision are expected from the TA students. Also, TA students' protocol data should reveal a significant percentage of failure attributions ascribed to the agent so that not all the blame falls on the student. However, TA students should accept personal responsibility for moving beyond the failure by ascribing some of the blame for failure to themselves and by taking specific actions to remedy the situation. Self students, on the other hand, should persist less and ascribe relatively more of the blame for failure to themselves.

Figure 5 shows an overview of the study and highlights differences between conditions. Each hour-long session was comprised of three phases: Study, Play, and Revise. During the Study phase, students read a passage about fever mechanisms then built concept maps to organize their knowledge on the topic. All students were familiar with concept mapping and had experience constructing maps in class as graphic organizers. However, the TA group was told that the purpose of building the map was to teach their agent, while for the Self group, the object of the concept mapping activity was to learn (for themselves).

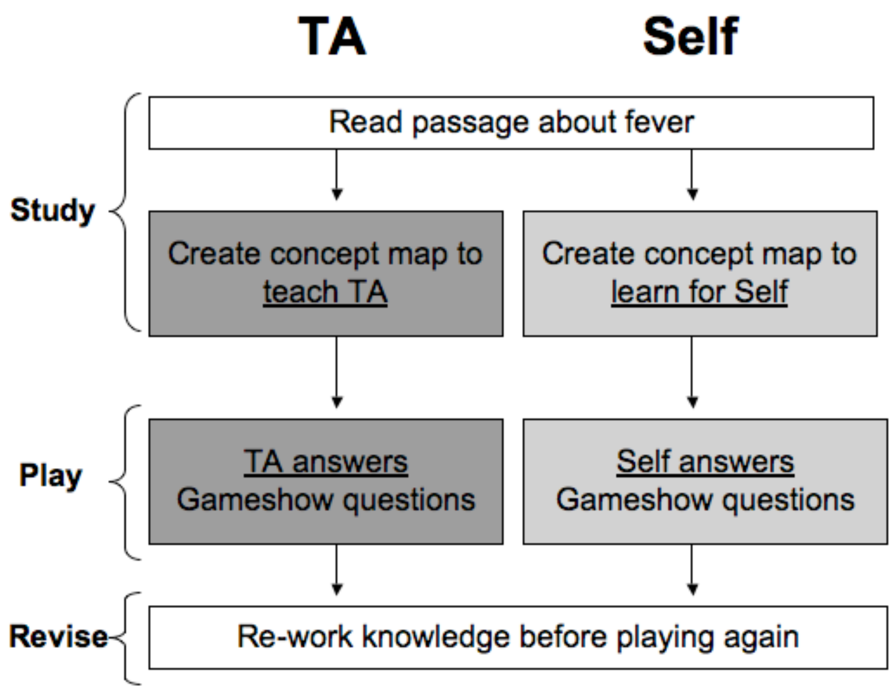

Figure 5. Outline of TA study. The study consisted of three phases. During the Study phase, all students read a passage about fever mechanisms then built concept maps. In the TA condition, they were studying for the sake of teaching their TA. In the Self condition, students were studying on behalf of themselves. During the Play phase, students played the game show and either the TAs or the students answered the questions in the game. In the Revise phase, students were given the opportunity to prepare for a harder round of the game show.

After students built their maps they moved on to the Play phase where they played one round of the game show alone. In the TA group, the agents answered the host's questions based on the maps, while in the Self group, the students themselves answered the questions by selecting answers from a drop-down menu. Game show questions were selected for their difficulty, ensuring that no student (or agent) would answer all questions correctly. As such, the game provided several opportunities for success and failure.

Students' think-aloud protocols during game show play revealed that TA students were much more likely to acknowledge failure than Self students. After getting a question wrong in the game show, TA students made far more statements of negative affect ("I'm sorry Diokiki" or "Ungh!! Why does he keep answering large increase!?!"). They also made more attributions of blame for the failure ("I didn't know this one" or "He got it wrong") whereas the Self students rarely mentioned failure. Thus, TA students paid greater attention to failures by expressing negative affect and making attributions.

An examination of how the TA students apportioned blame for failure revealed an even spread of attributions across the student and the TA. About 28% of attributions were made towards the TA ("He got it wrong"), 32% were directed to the self ("I didn't know this one"), and 40% were ascribed to some combination of both ("I, err… he didn't know this one"). In contrast, Self students, who did not have the luxury of an agent scapegoat to take the fall for them, made 100% of attributions to themselves. Thus, the TA seems to act as an ego-protective buffer by allowing another outlet for blame. However, not all of the blame fell to them; students did take some responsibility for the failure by making just as many self-attributions.

Furthermore, TA students acted on this sense of responsibility to their agents by choosing to revise their understanding. After receiving feedback in the game show, all students went on to the Revise phase where they were given the option of reworking their knowledge in preparation for a second, harder round of the game. During revision, students were allowed to review the passage, view and edit the concept map, or look over the game show feedback. A full 100% of the TA students chose to revise after the game show compared to only 64% of the Self students.

On the other hand, TA students' drive for revision is not surprising, given that the TA's performance is dependent on the maps. But this aspect of teaching a TA is an important part of moving beyond failure. For persistence to seem fruitful, there must be clear actionable paths or possible approaches for improvement. For the TA students, it is obvious how to increase the TA's knowledge – fix the links in its brain. For the Self students, it may not be so obvious how they can increase their own knowledge, especially for young children who do not have well-developed metacognitive skills. It is notable that 36% of Self students did not choose to revise at all; they did not even see the value in glancing at the reading again. Of the Self students who did choose to revise, they spent a mere 2.5 minutes doing so, compared to the TA students' average of 8.6 minutes. Perhaps by having the means for repairing the failure at their fingertips, TA students were motivated to persist longer at the task.

On the view advanced in this paper, the following describes my interpretation of how students learning for the sake of a TA persisted longer than students who were learning for themselves. Presenting students with the narrative of teaching an agent provided them with the tools for moving beyond failure. Since the TA was the one performing, not the students themselves, the TA could absorb part of the blame for failure, sparing students' sense of competence. At the same time, students felt responsible to their agents. They owed it to their agents to do better. This spurred them to continue work on the task. However, increasing blind effort without knowing specific actions to take towards improvement can lead to floundering. But TA students had obvious actions for revision and clear paths towards improvement, which made revision seem fruitful. Thus, the three motivational tools for moving beyond failure – an ego-protective buffer, acceptance of responsibility, and actionable paths – were all present in the Teachable Agent environment. Perhaps it is these three elements that ultimately led the TA students to acknowledge failures and attend to those failures by persisting at the task.

In this study, novice students learning with a TA displayed the same motivational behaviors as experts working on a task in their domain. Relative to Self students, TA students persisted longer, were more likely to revise, and made more failure attributions to external causes. Moreover, the TA enabled students to make progress in the task using specific strategies (i.e., editing the map). I propose that the agent provides students with the same set of motivational tools that experts have built up over many years of experience. However, the motivational tools of the agents are borne of different mechanisms. The agents use social motivators – another social being is there to take the blame and incite responsibility. The software provides the latter part – specific, well-structured ways to improve. For experts, the ability to move beyond failure may stem from a strong sense of self-efficacy, a well-developed personal interest, and domain-specific knowledge and skills. The students in this study did not have any of these qualities. Yet despite their lack of built-in motivational advantages, they were able to persist in the face of failure, with the support of the agent technology.

Nevertheless, getting students to persist in the face of failure is not always fruitful. For instance, perseveration on the same failing strategy is not a productive way to move towards success. This next study aimed to ascertain whether the failure-tackling environment created by the TA would lead to productive persistence that would enhance learning. From an interventionist standpoint it was also important to know whether the TA's motivational tools would prove effective in a classroom setting.

Do the motivational tools in the TA system enhance learning?

In this study, 8th grade students were again learning about how the body generates a fever (Chase, Chin, Oppezzo, & Schwartz, 2009). Sixty-two students from four different classes participated in the experiment; intact classes were randomly assigned to condition. The conditions were the same as in the prior study; either students were learning on behalf of their agents or learning for themselves. TA students were told: "today you are going to teach your agent about how the body generates a fever." They were instructed to "teach" their agents by creating a concept map that would represent the "agent's brain." In contrast, the Self group was told: "today you are going to learn about how the body generates a fever" by building concept maps, which was a fairly typical learning activity for these students. All classes were taught by the experimenters. Both groups used similar versions of the Betty software.

Students used Betty in the classroom over two days of instruction. Compared to the prior study, students had far more options in regulating their own learning. For the most part, students could choose how to spend their time in the system. They could read the resources, edit the map, take quizzes, query the map, play the game show, or use the chat tool whenever they wanted. Students tended to bounce back and forth between these activities. Every student action within the system was logged on the server, leaving a record of student behaviors and time spent using various Betty features.

Students in the TA group chose to spend more of their time on learning activities; about 50% of their time in the system was spent taking quizzes, asking questions, editing the map, and reading. In contrast, the Self group spent most of their time playing the game show and chatting; only 20% of their time was spent on learning activities. Looking at reading times alone, the TA group spent significantly more time reading (M_{TA} = 13.4 mins, M_{Self} = 8.4 mins), which is particularly impressive given the presence of other, more interactive attractors in their environment. These results demonstrate that TA students persisted longer at Betty's learning activities.

Moreover, on a paper-and-pencil post-test of factual, integration, and application problems, the TA group significantly outperformed the Self group on the harder questions – the integration and application problems. In Figure 6, the groups are split into high and low achievers based on prior science grades, demonstrating that the TA was particularly effective for low-achieving students. In fact, on harder questions, the low achieving TA students performed at the same level as the high achieving Self students.

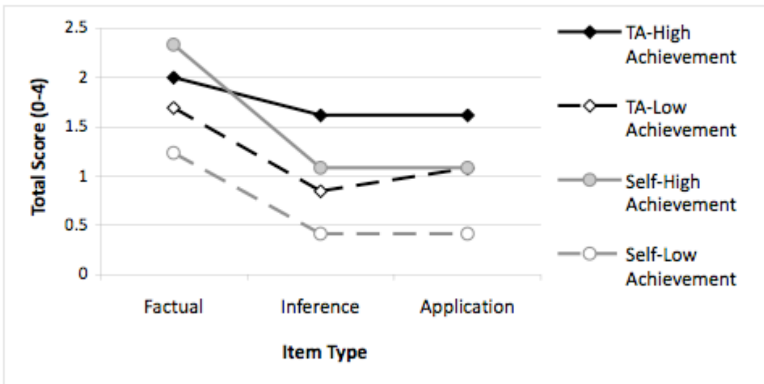

Figure 6. Post-test scores broken out by item type, achievement level, and condition. The low-achieving TA students performed similarly to the high-achieving Self students on inference and application questions. Figure adapted from Chase, Chin, Oppezzo, & Schwartz, 2009.

This second study confirms some of the findings of the prior study, that learning on behalf of a TA inspired persistence at learning-relevant activities, which surely contained some failure along the way. Moreover, this persistence seemed to provide significant learning gains, especially for low achievers. This makes sense since low achievers experience frequent failure and the motivational tools of the TA help students recover from mistakes. Moreover, the study provided initial evidence that the TA could work as an intervention in real-life classroom settings.

Conclusion

During their 10,000 hours of deliberate practice en route to mastery, experts have learned to cope with frequent experiences of failure. They have also managed to persevere through those failures, learning along the way. I examined experts as models of undying motivation, in an effort to design instructional interventions that would motivate students to get through difficult learning tasks where failure is likely.

A study with experts found suggestive evidence that they employ a suite of motivational tools while experiencing failure – an ego-protective buffer, acceptance of responsibility, and an actionable path for moving forward. However, experts' motivational skills are domain-specific; they do not display these three motivational mechanisms when working on a task outside of their domain. This domain-specificity makes sense given that experts' extensive knowledge in their area provides them with content-specific methods for moving beyond failure. Moreover, their self-efficacy and personal interest are domain-specific as well.

A viable classroom intervention for encouraging novices to adopt expert-like motivation is the Teachable Agent. A protocol study suggested that the Teachable Agent encourages novice children to use the same set of motivational devices that experts employ following failure. A classroom study demonstrated that teaching an agent leads to substantial learning gains, presumably through motivational means. The learning benefits of the TA are particularly robust for low-achieving students, who stand to gain the most from the failure-coping mechanisms of the TA.

I argue that three motivational tools promote persistence in the face of failure. However, definitive support for this claim requires further evidence. Studies that relate the presence or absence of each of these three tools to persistence outcomes would provide more direct evidence for the tools' existence. For instance, in a study designed to test the ego-protective buffer, the agent could spontaneously generate attributions after failure. In one condition the agent might say “Oops. I got that one wrong,” attributing blame to the agent, while in another condition, the agent could say “Oops. You got that one wrong,” attributing blame to the student. One could imagine similar studies that manipulate the responsibility and actionable path tools. Moreover, studies that systematically add or remove one or more of the tools could determine whether all three tools must be used in combination or whether each works in isolation.

The proposed suite of motivational tools is comprised of both motivational and cognitive components. The motivational literature could benefit from a comprehensive exploration of the relationship between motivation and cognition, as it relates to learning. Specific domain-related knowledge and skills could have a strong impact on motivation. For instance, perhaps experts’ knowledge of their domain enabled them to make external attributions. It takes a skilled eye to accurately assess the difficulty of a problem or to assess how external conditions precisely affect performance. When doing the math problem, some of the English experts naively assumed they were unsuccessful because they “didn’t know the equation,” thereby making internal attributions. Math experts, on the other hand, had the skill and knowledge to ascertain that no simple equation could be plugged in to the problem, rather, it would take some serious thinking and mulling over to generate the requisite proof. Given these circumstances, it makes sense that many math experts made external attributions to the conditions under which they were asked to perform, claiming they did not have enough time or access to external resources. This kind of interaction between knowledge and ego-protective mechanisms would be interesting to explore further. An important goal for future educational research should be to understand how motivation and cognition interact in the context of learning.

Another interesting question for further study is whether novices could learn, over time, to employ these motivational tools on their own, without needing an external support like the agent technology. There is some evidence that external social supports, like encouraging parents and competent teachers, are often present during the initial stages of expertise development (Barron, 2006; Sloboda & Howe, 1991; Sosniak, 1985), but eventually, experts are able to generate the motivational means for moving beyond failure by themselves. Many motivational theories address the phenomenon of how external motivators become internalized (Hidi & Renninger, 2006; Ryan & Deci, 2000) but not from the perspective of failure. Future research might examine whether students who have learned with the TA go on to self-generate the same suite of motivational tools when facing failure on learning tasks presented outside the TA environment.

In closing, I would like to share a brief story about my late father, Bill Chase, an eminent researcher in the field of expertise. My mother used to call him stubborn, but I believe his obstinacy was a testament to his unfailing persistence in the face of failure. For instance, one summer he ran 20 different variations on a single experiment until he finally got the materials just right, because he truly wanted to know the answer to his experimental question. I do not have evidence of the motivational tools that supported my father's dogged persistence, but I do know that his perseverance helped him to become an expert in expertise, making intellectual innovations that have changed the field of cognitive psychology. And so I hope my father can serve as an example to us all – an example of how tireless perseverance in the face of failure can lead one to develop expertise, make new discoveries, and leave a lasting impact on a field.

ACKNOWLEDGMENTS

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APPENDIX

Math problem

Taken from the 2006 William Lowell Putnam Mathematical Competition
(www.math.harvard.edu/putnam/2006/index.html)

Alice and Bob play a game in which they take turns removing stones from a heap that initially has n stones. The number of stones removed at each turn must be one less than a prime number. The winner is the player who takes the last stone. Alice plays first. Prove that there are infinitely many n such that Bob has a winning strategy. (For example, if $n = 17$, then Alice might take 6 leaving 11; then Bob might take 1 leaving 10; then Alice can take the remaining stones to win.)

Poem

This poem is taken from *Mistaken Identity* by Bruce Andrews and reprinted with the author's permission. (http://www.theeastvillage.com/t11/andrews/p1.htm)

1.

The situation has a situation
Electro-convulsive opinions eat us
Pig brink dollarization, the marriage of money gobble gobble money
Profit margin american cream dream cultures of vultures
A social predicament, the losers are self-preoccupied
Jellyfish FBI -- are you a vending machine?
Who fights the free? -- at least the exploited ones have a future
Dayglo ethics, corporate global chucksteak
Lose the flag, nightstick imitation value goosing me
Estados Unidos, suck o loaded pistol
Scale model blonde -- zoloft, paxil, luvox, celexa
Need money? -- it's easy, it's simple
Dot-commie foreskin arrevederci
Hot mark-up johnny on the spectacle
You as the human labor saving device
Culture, please -- all very non-missionary
Massive doses of dog tranquilizer -- to stop being reeducated
Hostesss of the ecosystem
Supoena the rocket so angsty
Self-catapulting PFC shimmy

Stiletto, spice it up -- live & die for the hell of it
Viva las vegans
Future suture stipend stutter
Only your insecurities make you jealous
Nasty simulacra -- you jerk, you forgot your pistol
Bunny potlatch -- Slam Slam Happens
Integrabby glisses up
You're the cowboys, we're the cattle
And Scrooge McDuck
The non-oligarchical wisecracker irritainment
Listen honey, we call it passive regressive
Dirt at crime scene -- cineplex moonshine foxtrot
White Collar Hairnet -- Burn-outs for Christ
Culture dead codehead down, pre-rave accessorizing the wick
Wallet had icing
Cops money satan
So contextual it squirted
A spore with a scholarship -- to reconcile the pre-ops
Bankroll some more pronouns bail to the chief
Contras got drug cash
Trustees in a world of pleat
The dotted line barks back to restooge our rights
PRISTINA -- rub our jobs on it
Red army faction -- well done, Society Members
The more reactionary & stupid, the more popular
Guillotine volunteers -- delighted
Eat the free-for-all, ephemera on cruise control
Immersicans
We just want it easy
Fat cats & middlemen, too many pills
Money to bork, licky-splitty totalizing enough