The Influence of Autobiographical Memory on Behavior, and Technologies that Support Both

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Abstract

Autobiographical memory is driven by self-enhancement motives that guide our behaviors. Reminiscence and reflection are memory processes that can induce self-enhancement, potentially leading to behavior change. We critically compare four theories of behavior change and the opportunities they provide for reminiscence and reflection. The ability to reminisce and reflect is currently limited by the fallibility of memory to provide accurate details of past events and behaviors. To address this, the final section of the paper discusses technologies that have been developed to capture these details, potentially supporting enhanced reflection, reminiscence, or behavior change. These technologies are rarely designed to simultaneously address both memory and behavior change, which presents new opportunities for a hybrid design space.

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In this paper, I argue that autobiographical memory shapes our behaviors, and technology provides new opportunities to support this relationship. To explore these connections, I review each of the main theories of autobiographical memory and behavior change and some of the technologies that have been developed to address each. I show that autobiographical memory processes are fundamentally driven to reduce discrepancies in our life story, and enhance our self-concept. By enhancing our view of our personal pasts, autobiographical memory drives goal achievement and behavior change (Conway & Pleydell-Pearce, 2000). However, this self-enhancement motive can shift from optimism to realism when confronted with overwhelming evidence of unsuccessful experiences (Conway & Tacchi, 1996). In this situation, our autobiographical memories become grounded in the belief that we are unable to achieve certain goals (to guide us toward attempting more attainable goals). This presents a major problem for behavior change when a person must persist toward their goals (e.g. if their health depends on it) despite their memories suggesting that they abandon this pursuit.

Reminiscence and reflection are two processes that can encourage self-enhancement by selectively retrieving and changing the way we think about our memories. Reminiscence is the simple remembering of autobiographical memories by bringing them back to mind, whereas reflection is remembering with deeper analysis and evaluation (Staudinger, 2001). Reminiscence has the potential to enhance the emotional intensity and awareness of positive memories (Bryant & Veroff, 2007). And reflection is useful for reshaping our emotionally negative memories to more positive evaluations (McAdams, Reynolds, Lewis, Patten, & Bowman, 2001). Thus, both processes can improve the self-enhancement function of autobiographical memory which

influences behavior change. To explore this potential further, we review each of four main theories of behavior change and find that there are many shared components and opportunities for reminiscence and reflection. These theories are Goal-Setting Theory, Theory of Planned Behavior, Self-Efficacy Theory, and the Transtheoretical Model.

For instance, Goal-Setting Theory is unique in its complexity, but shares some of its components with the Theory of Planned Behavior. *Commitment, ability, importance, social commitment*, and *self-efficacy* are Goal-Setting constructs which map on to the Theory of Planned Behavior constructs of *intention, actual control, attitude, subjective norms*, and *perceived behavioral control* respectively. Furthermore, all four theories share a *self-efficacy* component which illustrates the importance of this behavioral determinant. Since self-efficacy is largely determined by our memory of past events (Bandura, 1977), there is potential for reflection and reminiscence to influence these models by shaping our memories.

Specifically, reminiscence and reflection may impact behavior by resolving self-discrepancies that sap motivation, savoring success experiences, providing intrinsic feedback (and identification of skills that lead to change), as well as insight, causal reasoning, and more accurate source attributions that increase behavioral outcomes (Bandura, 1977; Bryant & Veroff, 2007; Gist & Mitchell, 1992; Locke & Latham, 2006; McAdams et al., 2001; Pennebaker & Chung, 2007; Sloan & Marx, 2004). We will describe these potential benefits in more detail in the behavior change section.

Lastly, while reminiscence and reflection support autobiographical memory and behavior change, they are limited by the fact that memory is fallible, reconstructive, and biased (Bartlett & Burt, 1933; Burgess, 1996; Loftus, Miller, & Burns, 1978; Schacter, 1999; Taylor & Brown, 1988). By not gaining access to all of the source details of events and behaviors, reminiscence

and reflection may be compromised. New technologies have been developed to capture personally relevant details of one's life to be accessed later for deeper understanding and change. This class of systems is called *personal informatics* which captures personally relevant information either for memory purposes or behavior change purposes (Li, 2012). For instance, some systems capture accurate details of events for enhanced reminiscence and reflection (Isaacs et al., 2013; Parks, Della Porta, Pierce, Zilca, & Lyubomirsky, 2012) while others increase awareness of past behaviors to guide future behavior (Bickmore, Caruso, & Clough-Gorr, 2005; Haug, Meyer, Schorr, Bauer, & John, 2009; Kollmann, Riedl, Kastner, Schreier, & Ludvik, 2007). Finally, we propose a new class of hybrid system that integrates key opportunities provided by both memory and behavior change systems. Thus while autobiographical memory, behavior change, and personal informatics may seem at face value like three unrelated fields, we show that their connections shed light and new understanding on each. On a practical level, we conclude that behavior change can be supported by memory processes and enhanced by technologies that are informed by both.

Autobiographical Memory

Our ability to be successful in our behaviors, depends critically on the functions of our memory (Conway, 2000). As we'll see in this section, *autobiographical memory* is a powerful goal-driven system that shapes our self-concept and ultimately our behaviors. While there are many different definitions of autobiographical memory, the consensus is that it is a system that encodes, stores, and retrieves information about personal events. The processes whereby we review these memories (either privately or to share them socially) are called *reminiscence* and *reflection*. Reminiscence involves simply remembering past events by bringing them back to mind. In contrast, reflection differs from reminiscence in that it adds an evaluative component to

process and understand personal memories and where they fit into one's life-story (Staudinger, 2001). Reminiscence is typically done with memories that are emotionally positive to enhance well-being (Bryant, Smart, & King, 2005), whereas reflection is often done with emotionally negative memories because these benefit the most from reflective evaluations (Pennebaker & Chung, 2007). Reflection and reminiscence are tools we can use to selectively retrieve and change the way we think about our memories, which in turn may influence our future behaviors. Before detailing these memory processes and their relation to behavior change, we first present an overview of autobiographical memory.

Autobiographical Memory Theories

Different branches of psychology are concerned with different aspects of autobiographical memory. For instance, while the developmental psychologist might be concerned with how autobiographical memory emerges, cognitive psychologists often focus on its frequency and functions. The developmental psychologists Nelson and Fivush (2004) proposed a social, cultural, developmental theory of autobiographical memory. Rather than viewing autobiographical memory as a separate system, they suggested that it is an emergent property of developmental growth (socially, culturally, and linguistically). For instance, as an infant develops a sense of self through language, consciousness, and narrative, temporal, and basic memory abilities, a property of this growth is said to be autobiographical memory. Cognitive psychologists such as Rubin, Rahhal, and Poon (1998) have focused more on the frequency of autobiographical memories across the lifespan than its development. For instance, they found a tendency for older adults to remember more events from their adolescence and early adulthood than other periods in their life (this phenomenon is known as the 'reminiscence bump').

Other cognitive psychologist like Pillemer (1992) and Bluck, Alea, Habermas, and Rubin (2005) have been concerned with the *reasons* why we have autobiographical memory which they call the directive, self, and social functions. *Directive* functions help us plan and direct our future behaviors based on our memory of past behaviors. Thus a reason why we have autobiographical memory is because it helps us be successful in future behaviors based on past experience. This paper will mainly focus on directive functions of autobiographical memory. A different reason we have autobiographical memory concerns *self-consistency*, where we remember our pasts so that we can understand who we are to preserve a sense of being a coherent person across time. A third reason for autobiographical memory is *social* functions, which are forms of sharing and bonding where memory of one's past can be disclosed to others for a sense of closeness. More recently, Williams, Conway, and Cohen (2007) have proposed a fourth function called "adaptive" which describes how autobiographical memory helps enhance a positive attitude and well-being. In response to such diversity in autobiographical memory research, Conway and Pleydell-Pearce developed a comprehensive model which encompasses multiple perspectives. This model is called the self-memory system, and is currently the most popular and widely cited model of autobiographical memory.

The Self-Memory System of Autobiographical Memory

When I was in the 3rd grade, I remember sitting in the play area of my classroom admiring all the toy cars that other students had brought from home. My parents had not bought me any toy cars to contribute, so in my jealousy I swiped a few cars and hid them in my pockets. I remember getting caught, and the intense shame and embarrassment I felt as the teacher called my parents and scolded me. I never stole from the other students again, and in a big way this was

my first lesson about honesty and moral values that played a role in shaping aspects of who I am today.

This classroom example from my personal past has all the classic features of an autobiographical memory and we will refer to it as we describe the main components of the self-memory system (SMS) (Conway & Pleydell-Pearce, 2000). The SMS is composed of an autobiographical knowledge base which is the storehouse of personal memories, and the working self, which controls what is stored and retrieved from the knowledge base.

Autobiographical Knowledge Base. The autobiographical knowledge base contains information about one's personal past that is indexed and organized into three levels of specificity: *Lifetime periods*, *general events*, and *event specific knowledge* (Barsalou, Neisser, & Winograd, 1988; Conway & Bekerian, 1987; Linton, 1986). See Figure 1 for a schematic of the three levels of specificity. The most general level is lifetime periods which represents knowledge about a theme in one's life like attending graduate school (school theme) or entering the workforce (work theme). A theme is a series of memories with common features that are linked together. In my classroom example, the lifetime period is "when I was in 3rd grade." Lifetime periods have a beginning and an end although there is often overlap with other themes and the boundaries are fuzzy. General events are more specific and heterogeneous than lifetime periods and can include information about singular events (e.g. my trip to Canada), or a cluster of related events linked across shorter time periods (e.g. learning to drive a car). The general event from my example is "sitting in the play area of my classroom." Lastly, at the most specific level is information about individual events usually in the form of sensory-perceptual and affective features. This is called event specific knowledge (ESK) such as the information I remember about all the little toy cars and the jealousy I felt for the other students. These three levels of

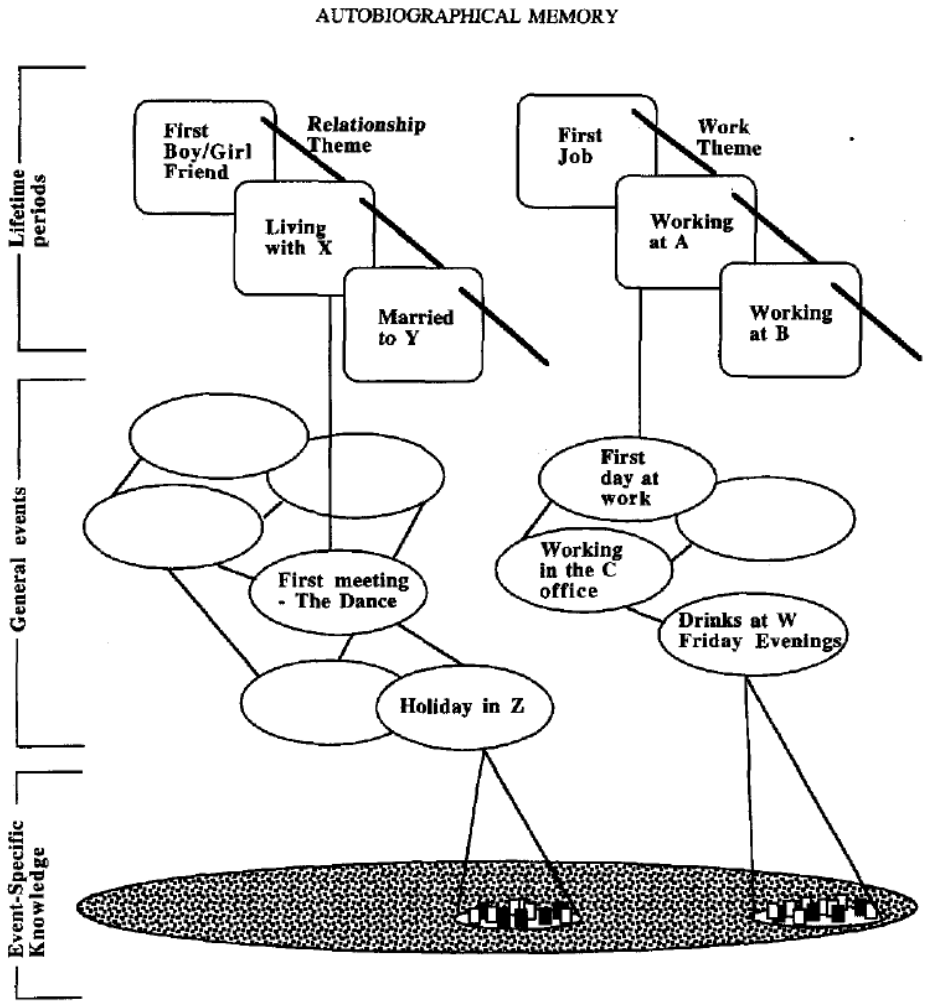

Figure 1. The three levels of specificity of autobiographical memories. From Conway, M. A., & Pleydell-Pearce, C. W. (2000). The construction of autobiographical memories in the self-memory system. *Psychological review,107*(2), (pg. 265).

specificity are organized hierarchically in the knowledge base and form the content of one's life story and identity (Conway, 2005; McAdams, 2001). In the presence of an evocative memory cue (such as a smell or revisiting a familiar location for instance) this can trigger activation of all three levels, and an autobiographical memory is retrieved (Conway & Pleydell-Pearce, 2000). For instance, if I see a small toy car in a shop window, this might cue the three levels of specificity (when I was in 3rd grade, I was in the play area, and I stole some toy cars and got caught) thus retrieving the full autobiographical memory.

The Working Self. While the autobiographical knowledge base is the container that holds our autobiographical memories, this contrasts with the working self which is a hierarchy of goals and self-motives that control what gets placed into the container (or what gets forgotten) (Higgins, 1987). The working self is selective and adaptive, it operates to reduce discrepancies between one's view of oneself and contrary evidence. In other words, the working self selectively organizes information that is stored in the knowledge base so that memories preserve a sense of self-consistency (Conway, Singer, & Tagini, 2004). For example, if I am looking for a job and I am reviewing past work experience, the working self will seek to retrieve memories that are consistent with my view of myself, and goal of finding employment. Memories of failures and set-backs I might have experienced occasionally during past employment should be less retrievable because they are incongruent with my positive evaluation of myself as an employee, which is critical to my goal of securing a job (Taylor & Brown, 1988). If the working self was not selective to reduce these self-discrepancies, I might remember the ESK of each set-back which would provide potentially damaging information to my sense of self (which in turn might inhibit me from applying to job opportunities). Beike and Landoll (2000) have demonstrated that when these inconsistent memories are occasionally retrieved (such as examples of goal failure for a lifetime period viewed as successful), people will justify the event as an exception and attribute more weight to the consistent memories (i.e. successes). In fact, the researchers also present evidence that the more effectively people revise and justify these memories to fit in with their lifetime period, the greater their sense of well-being. This is one explanation for why memory is considered to be a reconstructive process rather than an accurate representation of reality (D'Argembeau & Van der Linden, 2008). The working self protects

one's self-concept from the fragmentation of incongruent memories, by reconstructing these memories according to a consistent self-framework.

Additionally, the working self is driven to enhance the positivity of one's self-concept (D'Argembeau & Van der Linden, 2008). Because we seek to have a positive sense of self, discrepancies are resolved in the direction of self-enhancement. In other words, if memories conflict (such as emotionally positive and negative memories for an event), then the working self will store the positive memory and edit, fabricate, and even forget entirely the negative memory (Mitchell, Thompson, Peterson, & Cronk, 1997). This self-enhancement motive of the working self has been empirically tested in a large body of literature on positivity biases. For example, the *fading affect bias* explains a feature of memory where the emotion associated with negative events fades faster than emotions associated with positive events (Walker, Skowronski, & Thompson, 2003). Rapidly reducing the impact of negative events while preserving the impact of positive events serves a self-enhancement function by maintaining well-being (Walker & Skowronski, 2009). Also, people have a "rosy view" of the past in that they remember past events more positively than their actual experience of the event (Mitchell et al., 1997). Self-enhancement motives even influence our judgments of *when* past events occurred. Past failures are typically remembered as occurring further in the past than past accomplishments even when both events did not differ in when they actually occurred (Ross & Wilson, 2002). Furthermore, and consistent with this account, people tend to attribute past successes to themselves and past failures to others even when this is an inaccurate appraisal (Campbell & Sedikides, 1999). While not an exhaustive list, this illustrates the tendency for the working self to inhibit autobiographical memories that may threaten our self image.

Aside from protecting well-being, the self-enhancement function of the working self also greatly influences our behavior (Conway & Pleydell-Pearce, 2000). This is because a more optimistic view of one's past behaviors and capabilities increases the effort and persistence put into achieving current goals, which in turn produces greater performance outcomes (Felson, 1984; Singer & Salovey, 1993; Taylor & Brown, 1988). Another term for this belief in one's capabilities is *self-efficacy*, which is an important concept we discuss later in the behavior change section. Thus autobiographical memory has a self-enhancement function, to increase our self-efficacy, and a directive function, to guide our future behavior based off our self-efficacy (D'Argembeau & Van der Linden, 2008; Pillemer, 2003).

"Does Not Compute": Failures in the Self-Memory System. While the SMS clearly enhances our sense of self via our memories, there are situations that override these biases. When we experience consistent failure in achieving a goal, the SMS abandons its positive spin and favors realism over optimism (Conway, 2000). For example, there was a period in my life where I thought I wanted to pursue a career in astrophysics. However, I received low grades in every physics class I took and eventually it became clear that I was not suited to be in that field. Rather than the SMS manipulating my memories so that I believed I was a good astrophysicist, the overwhelming evidence to the contrary overshadowed such delusions. The goals of the working self must therefore be "grounded" in the autobiographical knowledge base, which means that we do not create goals that are completely unrealistic (e.g. continue to pursue astrophysics) when compared with the evidence our memories provide us (e.g. low grades in astrophysics classes) (Conway & Tacchi, 1996).

A limitation with the SMS theory is that the model does not explain when exactly and under what conditions does the SMS shift from optimism to realism. The model simply says that

in general the working self favors optimism and self-enhancement, but at some undefined point when there is 'too much' evidence to the contrary, the working self abandons its optimism and becomes grounded in these failures. While acknowledging one's failures is obviously an important part of learning and improvement, the mechanism that decides between blissful ignorance (self-enhancement) or realistic grounding (realism) is not well-understood. Furthermore, the SMS theory doesn't explain why this mechanism differs in people with mental illnesses like clinical depression, who tend to be less prone to enhancement biases. It is not yet known why those with depression are more realistic and experience less self-enhancement biases (Alloy & Abramson, 1988; Walker, Skowronski, Gibbons, Vogl, & Thompson, 2003). Lastly, the model describes a tendency toward optimism or a shift toward realism but does not consider memories that contain both. Surely it would not make sense to either remember only the positives, or only the negatives, when both might be useful to remember. For instance, I may view a previous employment experience as a successful period in my life, but if I am unable to remember some key set-backs, how will I be able to learn and improve. These important nuances are not explained by the SMS model.

This tendency for the SMS to shift from optimism to realism in the face of indisputable evidence can be helpful for guiding our behavior in directions that are more likely to be successful. The astrophysics example clearly illustrates when it might be adaptive to pursue more fruitful avenues (like becoming a psychologist), but this can actually be quite problematic in other situations. Take for example a person who wants to cut their sugar intake to lose weight but has experienced many failed attempts at dieting in the past. As a result of this evidence, the SMS would guide the person into believing they should abandon their dieting goal. This presents a

conflict between their SMS motivations and their health needs, reducing overall motivation for the behavioral change (Taylor & Brown, 1988).

An alternative to abandoning the dietary goal might be to shape their memories to be more consistent with the goal so that the SMS maintains its optimism. If we had a tool which would help this person transform their memories of failure to fit in with their positive self-concept (that they are capable of succeeding in their dietary goals) these discrepancies might be resolved in the direction of self-enhancement. For example, if they attribute their past failures to the fact that they didn't have health knowledge then that they possess now, they might feel they are better equipped to be successful. They might have a better understanding now of which foods contain the most sugar and interfere with weight loss. Therefore, their memories of failure could be construed as the result of outside factors (such as dietary misinformation) that don't threaten their positive self-concept. Furthermore, we might help this person emphasize and remember the instances in their past where they *were* successful to give these memories more weight (and thus more power to drive their behavior). As we will see, reminiscence and reflection are memory processes which help transform how we remember the past that may be useful to help nudge the SMS toward optimism and behavior change (Bryant et al., 2005; Pennebaker & Chung, 2007). Another major thrust of this paper is that technology offers powerful ways to enhance natural memory processes of reminiscence and reflection, which can lead to successful behavior change. We explore the role of technology in the personal informatics section.

Another example where the self-enhancement motive of the SMS breaks down is in post-traumatic stress disorder (PTSD). When a person experiences a trauma and develops PTSD, later they often suffer from intrusive and repetitive recall of the sensory-perceptual and affective details of the experience (Brewin, 1998; Ehlers & Steil, 1995). A trauma represents an

abrupt discrepancy with one's current self-concept, and this discrepancy triggers these intrusive memories until it is resolved. There are two mechanisms for resolving self-discrepancies which resemble Piaget's theories of assimilation and accommodation (Conway & Pleydell-Pearce, 2000; O'Sullivan & Durso, 1984; Piaget, 2014). The first is that the traumatic memory becomes transformed to fit in with one's current life story (assimilation). The second mechanism is for one's life story to change to accommodate the traumatic experience. Both of these possibilities can occur simultaneously as in the following example.

Take for instance a college student who has a full scholarship because she is a star player on the soccer team. Central to her self-concept are these themes of being a student and soccer player. If she were to experience a traumatic car accident that left her injured and unable to play soccer, this presents her with two contradictory concepts of self that are unreconciled. On the one hand she has her current concept of excelling in school and soccer (soccer self), and on the other hand she is faced with the new reality that she will never be able to play soccer again and will lose her scholarship (traumatic self). As a result, she is bothered by vivid flashbacks of the car accident that greatly interfere with her ability to function in her day to day life. The SMS model would explain these flashbacks as the result of ESK of the trauma that has not yet been organized and indexed into the hierarchy of general events and lifetime periods necessary to form a coherent life story (Conway & Pleydell-Pearce, 2000). The ESK knowledge of her car accident continues to be recalled because it's not yet clear how the experience fits in with her soccer self. Over time (or through therapeutic interventions such as reflection) her life story adapts to her current situation and the trauma becomes understood in terms of this story (Wildschut, Sedikides, Arndt, & Routledge, 2006). For instance, instead of playing soccer she may discover that she's quite good at coaching soccer and even enjoys this activity more (coach self). Thus her

car accident can be construed as an important event in her life that introduced her to new activities worthy of her passion. Effectively, her traumatic self becomes aligned with her coaching self to resolve the discrepancy and properly organize the event in her autobiographical knowledge base.

Another limitation with the SMS model is that it fails to explain why some people experience traumas they are unable to integrate while others integrate the experience rather quickly (Wortman & Silver, 1989). For instance, studies show that at least 65 percent of war veterans who experience horrific traumas never show any evidence of PTSD (Keane, 1998; Murray, 1992). What exactly are the factors that cause ESK to be improperly indexed to form PTSD? At what point does a trauma become severe enough to interfere with its integration? It's not clear whether it is the nature of the specific trauma that makes memories more intrusive and maintains discrepancies, or whether some people are dispositionally more susceptible to these experiences. While the precise factors involved seem to be unclear, reflection is a promising intervention to help facilitate reintegration of the memories, which we cover in detail later.

Similar to PTSD is a maladaptive mode of responding to distress called "rumination." Rumination is repetitively and passively focusing on the symptoms of a distressing event, such as one's negative emotions (e.g. I feel so sad, I just can't concentrate), rather than the solutions (Nolen-Hoeksema, 1991). In the framework of the SMS, this focus on the symptoms of distress occurs when only the most general aspects of a memory are accessed (the lifetime periods and general events). Unlike PTSD, a feature of rumination is overgeneralization, which means that ESK is not accessed, making it difficult for people to identify accurate sources of the distress (Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008; Watkins & Teasdale, 2001). Since general events and lifetime periods are accessed, this can trigger other thematic memories that exacerbate

the rumination (such as activating symptomatic thoughts about other problem relationships when ruminating about a divorce) (Lyubomirsky & Nolen-Hoeksema, 1995). Despite not accessing the specific information needed to understand and solve the problems they face, people claim they are ruminating as an attempt to problem solve (Carver, Scheier, & Weintraub, 1989; Lyubomirsky, Tucker, Caldwell, & Berg, 1999).

Rumination occurs when there are unresolved discrepancies between one's self-concept and evidence to the contrary (Martin & Tesser, 1996; Smith & Alloy, 2009). For instance, if a person views himself as having a good relationship with his son, discrepancies are created when he experiences occasional conflict and arguments in that relationship. Healthy functioning of the SMS would edit and adaptively forget these occurrences to preserve self-continuity. However, rumination is an unhealthy, maladaptive disposition that overrides the self-enhancement motives of the working self (Mor & Winquist, 2002). Thus he may experience an argument which is followed by repetitive thoughts about the symptoms of his distress (e.g. how he feels about the event) rather than the solution (e.g. what can I do to better this situation?). This narrow focus on symptoms leads to maladaptive cognitive styles such as depression, inaccurate attribution (attributing distress to incorrect sources) and pessimism (Nolen-Hoeksema et al., 2008). As previously discussed, our behaviors deeply depend on the functioning of our memory, and in the case of rumination, these memories are symptom-focused not solution-focused. Pessimistically ruminating about our memories becomes a self-fulfilling prophecy which saps motivation and interferes with behavior change (Lyubomirsky & Nolen-Hoeksema, 1993). Lyubomirsky, Kasri, Chang, and Chung (2006) demonstrated the seriousness of these implication when breast cancer ruminators reported delaying their initial symptoms to a doctor 2 months longer than breast cancer non-ruminators. Lastly, some of the most effective ways to break the cycle of rumination

are to improve the quality of thinking, for example by providing information that helps the person problem solve, increase mindfulness, and re-appraise the situation to fit in with their current self-concept (Nolen-Hoeksema et al., 2008; Segal, Williams, & Teasdale, 2012; Teasdale, Segal, & Williams, 1995). Next we discuss how reminiscence and reflection might be used to help solve some of these failures of the SMS system (such as the tendency to shift to realism in the face of failure experiences, traumatic memories, and rumination).

Reminiscence

Reminiscence is the simple remembering of autobiographical memories. While the field of autobiographical memory comes out of a classical memory paradigm (Rubin, 1999), reminiscence has its roots in clinical settings with elderly patients, even though reminiscence occurs throughout one's lifetime (Staudinger, 2001; Thornton & Brotchie, 1987). Reminiscence can be done privately (which is typically called *simple* reminiscence) or it can be done socially (which is called *social* or *informative* reminiscence) (Cohen & Taylor, 1998). What distinguishes reminiscence from reflection is that reminiscence is simply recalling or remembering past events without evaluating or analyzing them (Staudinger, 2001). For instance, when a grandfather recalls a moment from his childhood that he shares with his grandson, this is an example of social reminiscence.

Reminiscence comes from a clinical paradigm where it has been shown to have many psychological benefits. These benefits are obtained usually in the context of reminiscing about *positive* memories and not *negative* memories. For example, increased well-being is observed when participants are asked to reminisce about three good things that have occurred earlier in their day (Mongrain & Anselmo-Matthews, 2012). Additionally, correlational and experimental techniques have explored positive reminiscence (e.g. thinking about past successes, friendships),

showing that it increases perceived enjoyment of life (Bryant et al., 2005). Furthermore, Wildschut et al. (2006) showed that positive reminiscence increases positive affect and is often invoked as a way of coping with painful affective states (such as loneliness). Aside from coping with painful states, another proposed mechanism for the psychological benefits of positive reminiscence is called *savoring*. By savoring or attending to the pleasures and joys of the past, reminiscence enhances the emotional intensity and awareness of these positives (Bryant & Veroff, 2007).

On the other hand, when people reminisce about negative events this can lead to rumination and depression (Cappeliez & O'Rourke, 2006; Papageorgiou & Siegle, 2003). This may be because unlike reflection, reminiscence does not include an evaluative component, making it hard to process and resolve negative events. Since reminiscence facilitates savoring, reminiscence of negative events may facilitate revisiting or savoring of negative affect without any method to transform these feelings. Examples of unresolved negative reminiscence are Bitterness Revival, where difficult life circumstances and regrets are mentally revisited, and Intimacy Maintenance, where one ruminates about memories of a deceased significant other (Cappeliez & O'Rourke, 2006). In contrast, analyzing the events through reflection with a focus on solutions can help resolve the memories by developing "redemption sequences", which is a shift from a negative evaluation of the event to a more positive, triumphant one (McAdams et al., 2001). This is illustrated in our previous college student example whose injuries shifted her passions from soccer to coaching. After much reflection, she finds redemption from her car accident trauma because she learns that it provided her with a new, happier life. The construction of redemption sequences is associated with increased well-being (Wildschut et al., 2006). Thus while negative reminiscence can be maladaptive if the memory is never resolved, negative

reflection is adaptive because it helps resolve the memory. We turn our attention to a more thorough exploration of reflection in the next section.

Reflection

Reflection is the reviewing of autobiographical memories plus analysis that includes further explanation and evaluation. Analysis is most commonly facilitated via a therapist (which is called *life review*), or privately by writing about the event (called *emotional writing*). While reminiscence typically (but not always) focuses on positive memories, reflection is most often utilized in the context of negative memories. This is potentially because reflecting about positive memories has actually been shown to reduce health and well-being (Lyubomirsky, Sousa, & Dickerhoof, 2006). Subjecting the positive experience to a thorough analysis may reveal negative aspects that had not previously been considered, dampening its positive impact. Instead, the evaluative component of reflection is particularly suited for changing how one views the negative past, resulting in psychological and physical benefits.

Life Review. Butler (1963) was one of the first researchers to explore reflection on the negative past through what he called the "life review." He defined the life review as a process of mentally reviving and analyzing past experiences, particularly unresolved conflicts as the end of one's life is approached. The primary objective of the life review was said "to clarify, deepen and find use of what one has already obtained in a lifetime of learning and adapting" (Butler, 1974, pg 531). While he acknowledged that people can conduct a life review at any point in their lives, Butler preferred to view the intervention as a technique for facilitating 'successful aging' (Bohlmeijer, Smit, & Cuijpers, 2003; Butler, 1974). He described case-reports where the life-review was said to bring meaning to people's lives, prepare them for death, and encourage attributes of serenity and wisdom. Since Butler's original work, research has proliferated on the

life review to assess its potential for improving health across many different ages and demographics (Bohlmeijer et al., 2003). The life review has been shown to reduce depression (Pot et al., 2010), improve PTSD symptoms (Maercker, 2002), reduce the psychological impact of critical illnesses (Jones, Lyons, & Cunningham, 2003), and improve mood and cognition in people with dementia (Woods, Spector, Jones, Orrell, & Davies, 2005). Despite these studies, we do not know the exact mechanisms explaining why the life review is so successful. In the context of the SMS, maybe the life review helps reduce self-discrepancies by analyzing and changing one's view of the past. The life review is typically facilitated by a therapist (or in group settings), and in 2004, Serrano, Latorre, Gatz, and Montanes developed a standard protocol of the life review for therapists. Recently, reflection has been explored more privately through writing (instead of working with others) in a popular intervention called Emotional Writing.

Emotional Writing. The *emotional writing* paradigm was first introduced by Pennebaker and Beall (1986) to explore the benefits of reflection on negative events by having participants repeatedly write about past traumas. A typical emotional writing session lasts 15 to 30 minutes over the course of 1 to 5 days (Pennebaker & Chung, 2007). Studies of emotional writing usually occur in a laboratory setting where participants are randomly assigned to an emotional writing group (where they write about their feelings associated with a traumatic experience), or a control group that writes about superficial non-emotional events. The initial Pennebaker and Beall study reported long-term benefits of emotional writing as demonstrated by fewer health center visits in the following 6 months. To follow up these intriguing yet tentative findings, over 200 emotional writing studies have been published as of 2009 (Pennebaker & Chung, 2011). A meta-analysis of 13 emotional writing studies revealed high effect sizes for improved health (mean weighted effect size of d=.47) (Smyth, 1998). Since then, more meta-

analyses have largely supported these findings (see for example Frattaroli, 2006; Frisina, Borod, & Lepore, 2004; Harris, 2006). Emotional writing has been shown to increase immune response and antibody levels, as well as contribute to broader aspects of life such as grade point average, reemployment following job loss, and reduced absenteeism at work (Cameron & Nicholls, 1998; Francis & Pennebaker, 1992; Pennebaker, Kiecolt-Glaser, & Glaser, 1988; Petrie, Booth, Pennebaker, Davison, & Thomas, 1995; Spera, Buhrfeind, & Pennebaker, 1994).

But why is emotional writing so widely effective at improving health? By and large, the mechanism underlying emotional writing is still unknown. While many hypotheses have been proposed, the empirical support for these is just beginning to emerge. There is evidence that some benefits are derived simply from repeated exposure to the trauma. Repeatedly writing about the event is similar to exposure therapy, where facing the experience desensitizes the aversive emotional reaction to that experience. In support of this, Sloan and Marx (2004) showed that people exhibit the same physiological responses during emotional writing as those undergoing exposure therapy. During the first writing session, they experience a large spike in their stress response (as measured by cortisol) but this response reduces over repeated writing sessions.

However, habituation to the trauma seems to only be part of the picture as the act of writing about the trauma carries its own benefits (Krantz & Pennebaker, 2007). As mentioned before, PTSD and rumination can be thought of as resulting from self-discrepancies and discontinuity in one's self-concept. Thus a tool that can help resolve these discrepancies and properly organize the event in one's autobiographical knowledge base, should help reduce PTSD and ruminative symptoms. There is some evidence that writing about one's memories does in fact alter those memories (Schooler & Engstler-Schooler, 1990). Writing or labeling memories

also helps reduce their emotional impact. For example, Kehner, Locke, and Aurain (1993) found that after reading a depressing story, participants who labeled their emotions about the memory reported higher life satisfaction than those who didn't. Furthermore, emotional writing helps organize traumatic events into a coherent life narrative (Pennebaker & Chung, 2007). Support for this comes from Graybeal, Sexton, and Pennebaker (2002) who found that, across an emotional writing session, people organize and construct a life story in their writings. Also, words that are indications of insight (e.g. understand, realize) and causal reasoning (e.g. because, reason) increase over the course of a writing session and as they do, intrusive thinking about the negative event is reduced (Boals & Klein, 2005; K. Klein & Boals, 2001; Petrie, Booth, & Pennebaker, 1998).

Taken together, these findings suggest that the insight and self-understanding generated from emotional writing helps organize ESK of the trauma, potentially identifying accurate sources of distress (via causal reasoning), and resolving self-discrepancies. As a result, studies have shown that emotional writing is helpful for the management of PTSD symptoms, and reduces rumination (Sloan, Marx, Epstein, & Dobbs, 2008; Smyth, Hockemeyer, & Tulloch, 2008). Nonetheless, how emotional writing accomplishes this is not yet understood. Furthermore, when studies isolate and increase various potential sources for the benefits of emotional writing, additional benefits are often not observed. For instance, one proposed source of the benefits is a shift in perspective that provides insight on the event. However, when participants are asked to write from different perspectives (second or third person), this manipulation is no more beneficial than traditional unconstrained emotional writing (Seih, Chung, & Pennebaker, 2011). Another proposed source is an identification of the positive sides of the experience, but when people are asked to look for these positives, they receive less health

benefits than unconstrained emotional writing (Stanton et al., 2002). Thus many of these sources may be side-effects of the writing rather than actual mechanisms that create the improvements in health. Furthermore, we still don't know *when* emotional writing should be pursued for maximum benefit (e.g. directly after the event or after time has passed), and what type of person benefits most from emotional writing.

Let's return for a moment to the issue of behavior change and its relation to reflection. We have seen how behavior change is threatened by the tendency for the SMS to shift to realism in the face of failure experiences. Because positive reminiscence can increase the emotional intensity and awareness of positive memories (through savoring), this may be a useful tool for more optimistic self-enhancement functioning to support behavior change. We have discussed how having a more optimistic view of past behaviors affects our current behaviors and improves performance, thus reminiscence may help facilitate these outcomes. Of course, this process depends on being able to actually access some positive memories which can be used to reminisce and savor. In the case where people might have difficulty finding positive memories because the SMS has done a thorough job of editing them out, technology might provide a medium to help capture and then later remind people about these successes for enhanced reminiscence. Later in this paper we will explore systems that attempt to solve this problem and improve upon reminiscence.

Also, because reflection reduces self-discrepancies, this may be useful for memories that interfere with one's behavioral goals. The person who seeks to cut out sugar from their diet and has had past experiences of failure might use reflection to re-construe these memories. The causal reasoning facilitated by reflection might help her see that her past failures were caused by a lack of health knowledge (such as not knowing the sugar content of foods) that she now has

acquired. This redemption sequence gives her new determination to pursue her dietary goals. Furthermore, because reflection reduces rumination, and rumination interferes with behavior change, reflection might be useful for those seeking to change their behavior who suffer from this maladaptive coping style. We will return to these possibilities in the next section as we map out some of the most prominent theories of behavior change.

Behavior Change

Behavior change theories use different labels to describe similar driving phenomena of human behavior. Below, we describe the main premises and components of four of the most popular and widely researched behavior change theories: Goal-Setting Theory, Theory of Planned Behavior, Self-Efficacy Theory, and the Transtheoretical Model. The theories are ordered by those that are broadest in scope first, followed by theories that are progressively more specific and fine-grained. The last theory (Transtheoretical Model) is markedly different from the other three and adds a temporal dimension to the other three static models. The goal is to sketch out a conceptual map that coherently integrates the most important factors for behavior change. By understanding these factors, we will see how reflection, reminiscence and potentially other information about our pasts may be useful tools for behavior change.

Goal-Setting Theory

Goal-Setting Theory was formulated by Edwin Locke based on 400 studies concerned with goals, goal-setting, and how goals influence behavior change. The effects of goal-setting have been measured in laboratory and field studies, using both correlational and experimental procedures with numerous dependent variables (Locke & Latham, 2002). The theory was developed in an occupational setting to help increase employee productivity and performance of organizational or work-related tasks. In the framework of behavior change, increasing employee

performance is the behavior that goal-setting theory seeks to change. Because managers cannot constantly monitor each employee's motivation and progress, setting a goal is a practical tool to help increase performance without constant observation. A goal is defined as an aim of an action and performance is the objective measure of whether that goal has been missed, reached or exceeded. For example, a goal for a salesperson might be to reach a quota of sales each week. Goal-setting theory seeks to understand what types of quota should be assigned, and what moderating factors would encourage the greatest effort put forward by the salesperson. For instance, should the salesperson be given easier, difficult, general, or specific quotas? Are there important psychological factors to consider such as whether the salesperson believes they can achieve the goal, or whether they even consider the goal to be worthy of achieving in the first place?

Locke first began answering these questions in many small laboratory studies. For instance, one of the first goal setting studies asked college students to come up with possible uses of a given object (Locke, 1966). Performance was measured as the number of uses generated in a given time period. The students were given either an easy or difficult goal in terms of the number of uses they were to try and generate. Because students consistently generated more uses when their goal was difficult, this suggested that difficult goals encourage higher performance.

While Locke has mostly focused on laboratory studies to understand the different factors that affect behavior, since the latter part of the 1970s Gary Latham has extended the theory to occupational field studies. One of the first field studies he conducted was to encourage logging truck drivers to carry heavier loads to the mill (Latham & Baldes, 1975). Before the study, the loggers were averaging loads of about 60% of the legal weight limit. A difficult goal was set for the loggers to average 94%. As a result of the goal, the loggers made modifications to their

trucks that would allow them to more accurately predict the weight of the truck and get closer to the legal weight limit. Doing so increased their averages to 90% within 9 months, saving the company an estimated quarter of a million dollars. This suggested that difficult goals encourage higher performance even in the field, a result that has been replicated many time since (Locke, Shaw, Saari, & Latham, 1981; Mento, Steel, & Karren, 1987; Wood, Mento, & Locke, 1987). More recently, goal setting has been shown to be generalizable to a broad range of non-occupational settings such as sports and rehabilitation, and health interventions (Consolvo, Klasnja, McDonald, & Landay, 2009; Locke & Latham, 2002). For instance, Shilts, Horowitz, and Townsend (2004) have shown that goal-setting is an effective strategy for physical activity and dietary behavior change. Goal-setting has also been applied to the design of persuasive technologies to improve health outcomes (Bickmore et al., 2005; Consolvo et al., 2009; Gasser et al., 2006; Lin, Mamykina, Lindtner, Delajoux, & Strub, 2006). Across hundreds of studies, Goal-Setting Theory has been found to be broadly effective in many fields and on many levels (Locke & Latham, 2002; Mento et al., 1987).

In formulating goal-setting theory, Locke was most influenced by the work of Thomas Ryan (1970). Ryan's central premise was that the conscious setting of goals affects the action and effort put into achieving the goals. While Locke begins with this premise, because the theory is considered an open model (where elements are added as new discoveries are made), over the past decades the model has expanded to fit emerging empirical findings. There is no limit to the number of additions that can be made. The result has been the development of a rich understanding of multiple facets of behavior change. See Figure 1 for the major components of Goal-Setting Theory and their relationships.

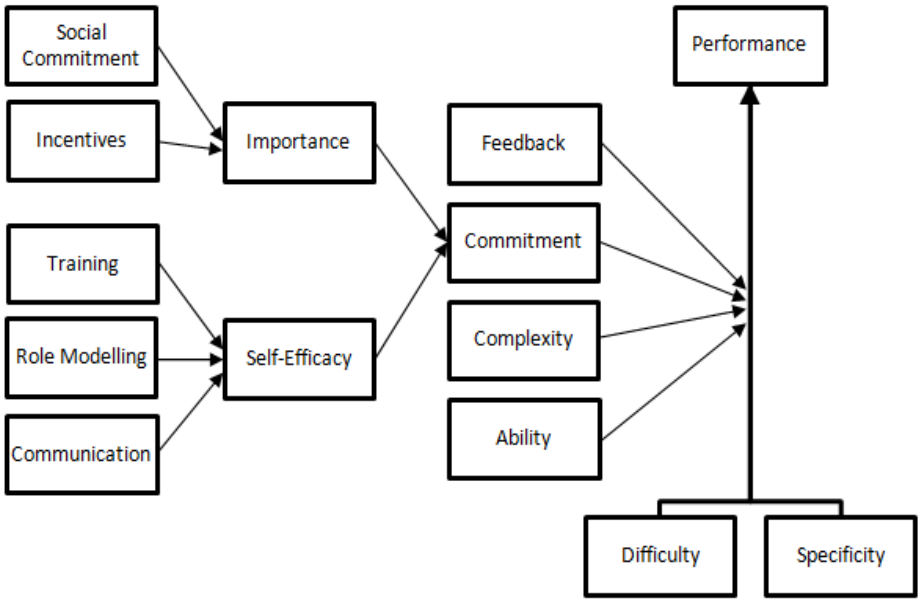

Figure 1. The major predictors and moderators of goal-setting theory.

While there are multiple considerations that affect performance and the effort put into achieving goals, the two most central claims of Goal-Setting Theory are that there is a linear positive relationship between (1) performance and difficulty of the goals and (2) performance and specificity of the goals. Goal-Setting Theory works as follows: once a goal is created, this represents a discrepancy between the current state of the person and the goal-state that the person seeks to achieve. We have previously seen how memory is goal-driven to reduce self-discrepancies, and this also drives our behavior. Going back to our salesperson example, if she is currently averaging 10 sales of her product each week, and she sets a goal of 15, there is a discrepancy of 5 sales which she seeks to attain to feel the satisfaction of goal achievement. Thus, achieving a goal confers a certain type of satisfaction with closing the gap between where one is and where one wants to be. This is why difficult goals are said to be motivating because they require more effort to reach satisfaction than easier goals. A goal of 20 product sales per week should be more motivating than 15 product sales because it is more difficult. Another way

to say this is that difficult goals have more instrumentality, which means that they offer greater rewards and inspire more effort as a result (Mento, Locke, & Klein, 1992). Many studies have confirmed this relationship between difficulty and performance and meta-analyses reveal goal difficulty effect-sizes that range from .52 to .82 (Locke & Latham, 1990). Specific goals (such as 15 product sales per week) increase performance as opposed to vague goals such as asking people to "do your best." Vague goals are open to interpretation and lead to wide variability in deciding what is an acceptable level of effort and performance. Specific goals are superior because they have a clear external referent which guides behavior.

While *difficult* and *specific* goals encourage greater behavior change, there are many caveats that moderate these relationships. Following are some of the most important moderators of the relationship between difficulty/specificity and performance.

Commitment. One of the most influential moderators of the relationship between difficulty and performance is *commitment*. Commitment represents how willing the individual is to try to achieve the goal, and is most typically measured by standard questionnaires such as the five-item Goal Commitment Scale (H. J. Klein, Wesson, Hollenbeck, Wright, & DeShon, 2001). Difficult, specific goals only influence performance when there is a high level of commitment from the individual (H. J. Klein, Wesson, Hollenbeck, & Alge, 1999). The two factors that contribute the most to commitment are the degree to which the individual values the goal positively or negatively (*importance*), and their belief that they can achieve the goal (*self-efficacy*). Importance is primarily influenced by *incentives* (usually monetary) and *social commitment* (or peer pressure). Self-efficacy is influenced by *training* (to encourage mastery and give the experience of successfully completing goals), *role-modeling* (seeing that others can

achieve the goal increases one's own belief in capabilities), and *communication* (to expresses confidence and encouragement).

For example, suppose a postal worker is assigned a difficult and specific goal by a manager to process and ship 100 packages in an 8 hour work day. Previously the worker was averaging around 50 packages a day. Goal-setting theory predicts that this goal will increase performance (more packages processed) but only if the worker is committed to the goal and willing to try to achieve it. He finds the goal important, because he will receive a raise if he achieves it (incentives) and his peers are already averaging 100 packages and he doesn't want to let his team down (social commitment). However, doubling his productivity seems like an impossible endeavor and he is concerned he will be unsuccessful (his self-efficacy is low). Despite believing that the goal is important, his self-efficacy is low so his commitment to the goal suffers. Thus a manager might assign him to training or role-modeling to see how his peers accomplish the goal and to get his own experiences of gradually mastering the goal. Lastly, as he makes strides in his training, the whole team provides him with encouragement and expresses their confidence in his abilities to further boost his self-efficacy. Having developed a strategy to strengthen the components that were lacking (self-efficacy in this example), the worker is now able to achieve his goal. Because self-efficacy is such an important factor in most behavior change theories, we will discuss it in more detail in the Self-Efficacy Theory section.

Ability. Ability is probably the most intuitive moderator in that difficult, specific goals are motivating only as far as they are within the limits of what a person can accomplish. The linear positive relationship between difficulty and performance first proposed by Locke holds up until ability limitations are reached after which performance begins to level off. Bavelas and Lee (1978) demonstrated this by asking participants to name as many objects they can think of within

a given category (such as “heavy”, or “white”). Participants were given increasingly difficult goals to list more and more objects within the time limit. Some participants were told how much time they would have to list the objects, and others were given no information about timing. Figure 2 presents a graph of their data showing that performance (quantity of objects) increases linearly with difficulty (goal level) until limits of ability are reached. After the boundaries of ability are exceeded, performance levels off.

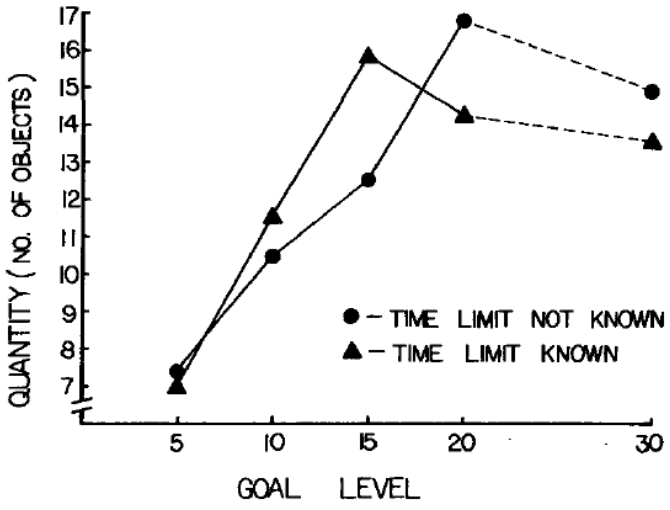

Figure 2. Mean effect of difficulty level on performance for participants who were aware of the time limit versus those who were not. From Bavelas, J. B., & Lee, E. S. (1978). Effects of goal level on performance: a trade-off of quantity and quality. *Canadian Journal of Psychology/Revue canadienne de psychologie, 32*(4), (pg. 224).

Complexity. While specific goals are considered preferable to vague goals, there are some scenarios when the opposite is true. For instance, when the goal is overly complex people experience performance anxiety as they develop disorganized strategies for the goal’s attainment (Locke & Latham, 2002). This was demonstrated by Earley, Connolly, and Ekegren (1989) by asking participants to predict the costs of random business stocks within $10 of the actual price. The task was complex because participants had to integrate multiple levels of information to

make these estimates. As a result, participants scrambled to develop strategies for task success and performed worse than a group that was given a goal to do their best. However, this anxiety only debilitates performance when the goal is focused on achievement, rather than learning the requisite skills required for achievement. For example, students who are only focused on getting an "A" grade in a course are performance oriented, versus students who focus on learning the material and skills required for the course. When achievement is the objective, this is called Performance Goal Orientation (PGO) and differs from goals that are focused on developing strategies and understanding of skills required to reach the goal. The latter is called Learning Goal Orientation (LGO) when the focus is on learning skills rather than achieving end-results. Goal-Setting Theory suggests that learning-oriented students will be more interested in the course and inspired to exert more effort than performance-oriented students who are limited by their "tunnel vision" (Locke & Latham, 2002). Many studies have explored this relationship and have consistently found that LGO results in greater effort and performance than PGO (Locke & Latham, 2002, 2006).

These same effects are found in a similar theory of motivation called self-determination theory (Deci, 1971). This theory differentiates between *intrinsic* motivation, which refers to working toward goals because they are inherently interesting, and *extrinsic* motivation, which refers to working toward goals for some separable outcome. In other words, intrinsic motivation refers to doing activities that are interesting in and of themselves (like learning) as opposed to trying to achieve an outcome because of its instrumentality (like grades). Consistent with LGO and PGO in goal-setting theory, intrinsic motivation is found to improve performance over extrinsic motivation (Schmuck, Kasser, & Ryan, 2000).

Feedback. Feedback is an important and highly researched moderator of goal-setting because difficult, specific goals encourage greater performance and motivation with feedback than without (Becker, 1978). When given feedback, people normally increase their effort or attempt new task-strategies to meet their goals (Matsui, Okada, & Inoshita, 1983). Returning to our postal worker example, if his goal is to process 100 packages and he has only processed 30 when the day is half completed, he will need to increase his effort or find new strategies to make up for lost time. There are two main types of feedback which are *intrinsic* (self-generated) feedback and *extrinsic* (externally-generated) feedback (Ivancevich & McMahon, 1982). Intrinsic feedback is more effective at increasing behavior change than extrinsic feedback such as a progress reports from a supervisor because intrinsic feedback requires self-monitoring which makes one more aware of success experiences and progress toward the goal (Gist, 1987). The person may not connect as well with external feedback and embrace it as a tool for change as when generating this feedback themselves. Becoming more aware of one's progress toward the goal, increases self-efficacy, which in turn increases task performance and effort (Gist, 1987).

There are more moderators, mediators, and antecedents in Goal-Setting Theory that are too numerous to discuss in this paper. The components we have covered represent those which we feel are most central to the theory and highly researched.

Autobiographical Memory and Goal-Setting Theory. Reminiscing and reflecting on autobiographical memories may have potential for influencing critical aspects of goal-setting theory which impact behavior change. Remember that we defined reminiscence as simply remembering past events without analysis. While this has yet to be empirically tested, it is possible that reminiscence may provide a similar experience as training and role-modeling for increased self-efficacy and behavior change. Training gives the experience of successfully

completing goals so that people are more likely to believe in their efficacy. Similarly, reminiscence can help a person remember and savor their past experiences of success, also contributing to efficacy. Alternatively, reminiscence might be more similar to role-modeling than training because it reminds people of the successes of a past version of themselves. It's unclear whether these success experiences are interpreted in first or third person and closer to training or role-modeling. The third determinant of self-efficacy, *communication* (to express confidence and encouragement), might be supported by reflective technologies that empower people to create records (with words of encouragement to themselves) that they will reflect on at a later point. We explore this potential further in the *technology-mediated reflection* section.

Recall that we defined reflection as analyzing and explaining specific events from our past. Following this definition, self-generated feedback is fundamentally a type of reflection since both entail self-monitoring and evaluation of past events. When reflecting on past failures and successes, this process can serve as intrinsic feedback to adjust goal achievement strategies and increase effort. Intrinsic feedback through reflection is not only more effective than extrinsic feedback (from a supervisor for instance), but it is also available any time a person wants to reflect since it is not dependent on others.

Performance is increased when seeking to learn the skills to achieve a goal (LGO) versus the tunnel vision associated with seeking just the achievement (PGO) (Locke & Latham, 2002, 2006). This is a limitation with goal-setting theory because much of the occupational domain that the theory concerns itself with is focused on performance objectives (to increase the company's bottom line) rather than learning objectives. As a result, employees might not develop appropriate strategies to meet their performance goals, and this failure has been shown to increase unethical behaviors such as fudging numbers and lying to customers for sales (Ordóñez,

Schweitzer, Galinsky, & Bazerman, 2009). Because reflection requires active evaluation of the past, provoking causal reasoning, understanding, and insight, this might increase LGO and the effort put into achieving goals (K. Klein & Boals, 2001; Pennebaker & Chung, 2007; Petrie et al., 1998). In fact, Seibert (2000) showed that reflection does facilitate greater learning of goal achievement strategies. Anseel, Lievens, and Schollaert (2009) showed that reflection is more likely to improve performance when external feedback is provided than without external feedback. While reflection does facilitate learning, people may learn strategies that are inappropriate if they are not provided with some guidance along the way. Thus external feedback may be an important moderator to keep participants on track when using reflection to enhance LGO (and ultimately performance). To sum up, reflection may generate intrinsic feedback and greater learning of goal-achievement strategies, which can be further supported by the guidance of extrinsic feedback for behavior change.

Goal-Setting Theory is explicitly concerned with conscious decisions to achieve goals. One of its limitations is that people can take action without consciously being aware of what motivates them (Locke & Latham, 2002). Habits and addictions that often entail a certain amount of automaticity and unconscious reaction to impulse are outside the scope of Goal-Setting Theory. This makes reflection particularly interesting because of its ability to increase self-understanding which may shed light on previously unattended to aspects of behavior. For example, a person may find himself smoking more cigarettes than he desires with little awareness as to why he is triggered to do so. The causal reasoning that is encouraged by reflection may help him identify that a particular relationship in his life triggers him to smoke more, and he may have some success changing this habit by managing this relationship.

Theory of Planned Behavior

While Goal-Setting Theory provides us with a comprehensive understanding of the factors that influence behavior, it becomes difficult to consider every component when designing behavior change interventions. The complexity serves a holistic purpose, but lacks the parsimony of other models that emphasize a few significant components. The Theory of Planned Behavior (TPB) is such a model, and while many of its components are similar to those of Goal-Setting Theory, TPB includes only those factors that have the highest predictive power for behavior change (Ajzen, 1991). See Figure 3 for the components of the TPB in relation to the goal-setting model.

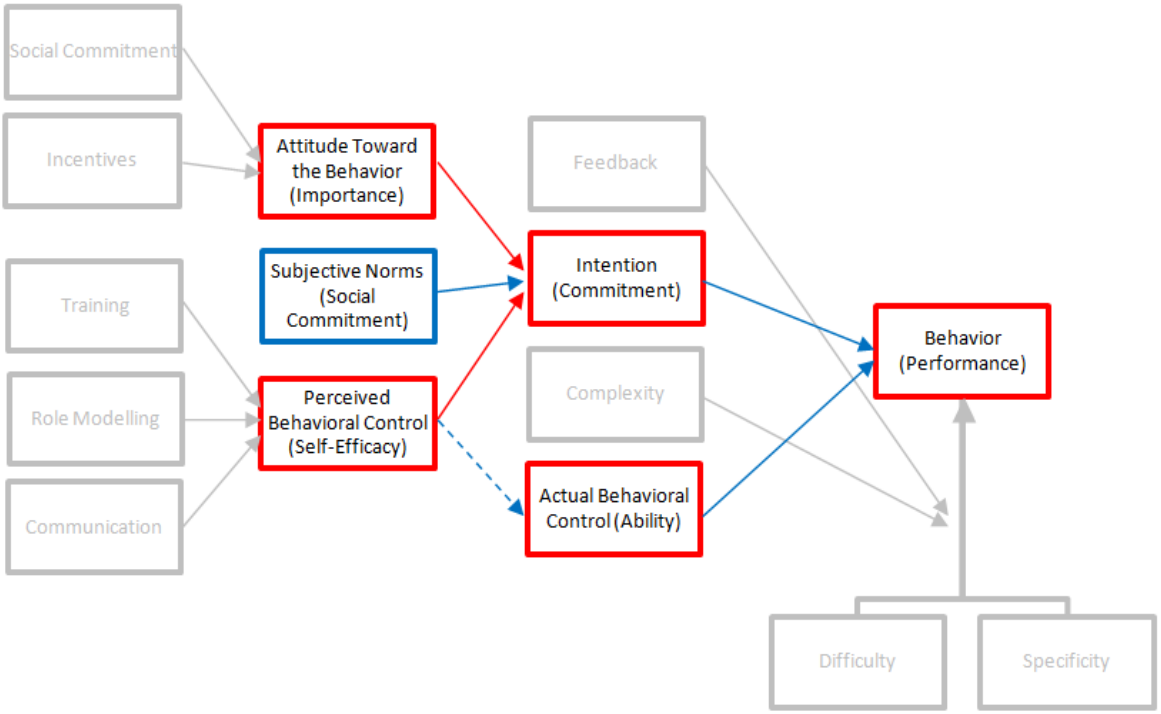

Figure 3. The components of the Theory of Planned Behavior (shown in red and blue). In grey are the components of goal-setting theory not shared with the TPB. Red represents shared components, and blue represents TPB additions that are different from goal-setting theory. Note: While Subjective Norms is theoretically the same as Social Commitment, this node is duplicated in blue to show that it is placed at a different location in the TPB model than in the goal-setting model.

The focus of TPB is on the link between beliefs and behaviors and does not emphasize goal-setting. Thus, there are no components to explain the influence of goal difficulty or specificity. While in principle the TPB could be applied to any of the occupational goals typically associated with goal-setting theory, the emphasis is on changing behavior rather than performance and goal achievement. For example, the TPB has been used to predict the mother's choice in newborn feeding methods (breast versus bottle) which is more accurately described as a behavior than a performance (Manstead, Proffitt, & Smart, 1983).

TPB has been used to predict behavior in a wide range of domains such as political behaviors (participating in an election), health behaviors (losing weight and drinking), and ethical behaviors (shoplifting and lying) (Beck & Ajzen, 1991; Schifter & Ajzen, 1985; Schlegel, DAvernas, Zanna, DeCourville, & Manske, 1992; Watters, 1989). The theory was developed to explain conscious behaviors as opposed to habits that are more reflexive (such as smoking cessation) and performs worse for these behaviors (Verplanken, Aarts, Knippenberg, & Moonen, 1998). The majority of research on the TPB is concerned with the predictive power of the model for behavior change (Armitage & Conner, 2001). Regression techniques are often employed in field studies to understand how different components influence behavior as an outcome variable. The most common behaviors that are measured are health-related, and aside from assessing predictive power some studies use the model to help develop health interventions (see Godin & Kok, 1996 and Hardeman et al., 2002 for health related meta-analyses of TPB).

The TPB is an updated version of the Theory of Reasoned Action (TRA), both of which were created by Icek Ajzen (1980, 1985). As with Goal-Setting Theory, the TRA and TPB are models about conscious or "reasoned" decisions that affect behavior. All of the components of the model are measured through self-report questionnaires with only a few studies introducing

objective measures such as official documentation of behaviors like paying taxes (Hessing, Elffers, & Weigel, 1988). The vast majority of these questionnaires have been developed by the researchers and lack standard validity and reliability metrics (Beck & Ajzen, 1991; Dzewaltowski, Noble, & Shaw, 1990; Terry, Hogg, & White, 1999). Because the TPB has been applied to very different behavioral domains, there is no consensus about which questionnaires should be employed in which contexts (Ajzen, 2002). This has led to methodological differences that potentially influence the variability of reported results (Armitage & Conner, 2001).

In the TPB model, behavior is influenced predominantly by *intention* which is defined as readiness to perform a given behavior and how much a person is willing to work to succeed in achieving that behavior. Intention is influenced by *attitude toward the behavior* (a favorable or unfavorable evaluation), and *subjective norm* (the perceived social pressure to engage in the behavior). In turn, both attitude and subjective norm are influenced by the most salient, immediately accessible beliefs that one has about the behavior. It is assumed that people hold a multitude of different beliefs about the given behavior, but only some of these are salient and influential at any one time. For instance, if a student does well on a midterm without having done any of the class reading, the salient belief that reading is not important for grades may affect his attitude toward the class, intention, and finally behavior (he may give up on reading the class materials altogether).

After Ajzen developed the TRA, it became clear that one glaring limitation needed to be addressed. The model only fits behaviors that are entirely within the control of the individual. For example, a person may have high intentions to lose weight, but if they are not educated about which foods are healthier than others, their intentions will have a limited influence over their behavior. As a result, the TPB was developed which is exactly the same as the TRA except it

adds two components that deal with one's control over the behavior. *Actual behavioral control* refers to the extent to which a person has the requisite ability (i.e. time, resources, money, physical ability, knowledge, cooperation, etc.) to achieve the goal, and along with intention, the two are immediate predictors of behavior. Because actual behavioral control can be difficult to measure, a proxy for this construct is called *perceived behavioral control* (PBC). PBC is conceptually the same thing as self-efficacy (although operationally they are usually measured by different survey instruments), and refers to the person's beliefs in their ability to perform a given behavior.

While it is of course possible for people to under or over-estimate their perceived ability to perform a behavior, in general PBC is a good approximation for actual control and is often measured with intention as predictors for behavior. For instance, people tend to overestimate PBC when considering weight loss and getting an 'A' grade in a class which makes these behaviors more difficult to predict with the TPB. Lastly, while PBC predicts actual behavioral control, it also directly influences intention. As we'll see in the next section, self-efficacy (PBC) directly increases one's willingness to work toward the goal (intention).

To sum up, behavior is influenced by intention and actual behavioral control. Actual behavioral control is predicted by perceived behavioral control. And intention is predicted by attitude, subjective norm, and perceived behavioral control. Now that we've covered the main elements of the TPB, the reader might have begun to notice some overlaps with Goal-Setting Theory. Intention from TPB, seems to involve the same willingness to work toward the goal as commitment from Goal-Setting Theory. Attitude toward the behavior involve similar value judgments as importance. Actual behavioral control refers to the same resources and limitations as ability. Perceived behavioral control is conceptually the same as self-efficacy. And subjective

norm consists of the same peer influence as social commitment. Also, when conducting regression analyses on the various components of the TPB, attitudes and perceived behavioral control have consistently been shown to be most predictive of behavior, while social norms is markedly less predictive. Goal-Setting Theory may shed light on this finding because the social commitment node is a level below the self-efficacy and importance nodes. In other words, instead of all three components predicting intentions independently, Goal-Setting Theory would suggest that subjective norm is instead an antecedent to attitudes which in combination with PBC would be the greatest predictors of intention. This modified version of the model should be subjected to further regression techniques to determine if it represents a more accurate fit.

While the TPB is missing some of the nodes in Goal-Setting Theory such as incentives and level of difficulty, it sacrifices thoroughness for simplicity which is immediately attractive to those designing health interventions. This is evidenced by meta-analyses that show the TPB is used more often in internet-based health interventions than any other theory (Webb, Joseph, Yardley, & Michie, 2010). We explore some of these technological interventions later in the paper.

Autobiographical Memory and the Theory of Planned Behavior. The TPB has similar limitations as Goal-Setting Theory, primarily in that the model is applicable only to conscious and reasoned decisions. Unconscious, automatic behaviors are not predicted by the model. As mentioned before, reflection can generate insight which might reveal aspects of behavior that were previously inaccessible. Said another way, because behaviors in the TPB are the result of salient beliefs, reflecting on less salient and subtler introspections might provide access to new antecedents of change that are lacking in the model.

Furthermore, while not explicitly addressed in the TPB, researchers have noted the importance of the past in predicting future behavior (Conner & Armitage, 1998). Because past successes and failures influence one's belief about their ability to succeed in the future, Ajzen has suggested that Perceived Behavioral Control mediates the influence of the past on future behaviors (Ajzen, 1991)..Thus, reminiscing about one's past successes may increase perceived behavioral control and in turn encourage change. Because PBC (self-efficacy) is so important to the TPB, let's refine our theoretical map of behavior change and explore how self-efficacy alone contributes to behavior.

Self-Efficacy Theory

Self-Efficacy Theory was developed by Albert Bandura as part of a larger theory called Social-Cognitive Theory (SCT) which describes human motivation and behavior as being driven by the interaction of behavioral factors, personal (and cognitive factors), and environmental factors. SCT is primarily concerned with observational learning in that all our behaviors are said to be shaped by our observation of other's behaviors. By observing others we learn how the new behavioral pattern is to be performed. Furthermore, by learning the consequences and results of our own behavior, we learn which behaviors are appropriate and our beliefs are shaped about our capability to perform these behaviors. This is a special case of SCT where instead of observing others, we observe ourselves to modify our beliefs and behavior. Self-efficacy is central to this theory in that our observations of self and others shape our beliefs in our ability to perform the behavior, which is what defines the term. Many studies have shown that increasing self-efficacy subsequently increases the effort and persistence put into achieving the goal or changing the behavior (Bandura, 1977; Conner & Norman, 2005; Luszczynska & Schwarzer, 2005; Schunk,

1990). Because of this, self-efficacy is an important component of all major behavior change theories.

While Goal-Setting Theory comes from an occupational setting, and Theory of Planned Behavior has its roots in social psychology, Self-Efficacy Theory was originally proposed for psychotherapeutic applications. For instance, when using desensitization and exposure therapies to address a phobia, the individual is given experiences that they can successfully navigate frightening situations. These success experiences raise their self-efficacy which in turn reduces avoidance behaviors and phobia symptoms (Bandura, 1977).

Because self-efficacy beliefs are driven by our observations of self and others, Bandura has proposed four informational cues which influence this process (Figure 3 shows how these cues fit into the larger framework of goal-setting theory):

1. Enactive Mastery (also called Performance Accomplishment). These are experiences the individual has of herself successfully achieving the behavior.
2. Vicarious Experience (also called Modeling). These are experiences of others, such as role models, who show by example that the behavior can be accomplished. The more the individual relates to this person, the greater influence they will have on self-efficacy by showing how to succeed.
3. Verbal Persuasion (also called Social Persuasion). This is when others provide encouragement and persuasive communication with the intent of motivating the individual, and increasing their belief in their capabilities.
4. Physiological Arousal. When we are aware of physiological cues such as increased heart-rate and sweating before delivering a speech, we may interpret these cues in different ways. Some people will recognize this as a common experience, and others

will view such nervousness as a sign of their incompetence. Therefore, these cues can provide feedback which influences self-efficacy.

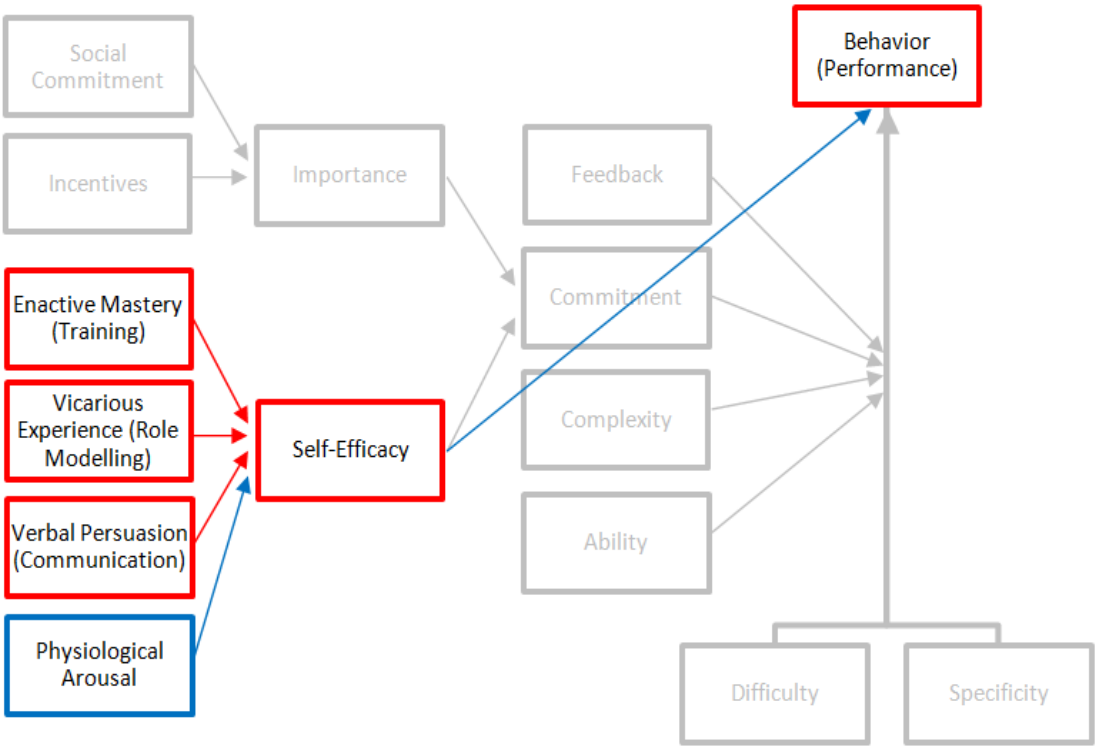

Figure 4. The components of self-efficacy theory (shown in red and blue). In grey are the components of goal-setting theory not shared with the TPB. Red represents shared components, and blue represents self-efficacy theory additions that are different from goal-setting theory.

Much research has gone into investigating these informational cues, and have found that their importance for determining self-efficacy are ordered as above from most to least important (Bandura, 1977). In other words, Enactive Mastery influences self-efficacy far more than the other cues. We see some overlap with Goal-Setting Theory which identifies the determinants of self-efficacy to be training in success experiences (enactive mastery), role-modeling (vicarious experience), and communication that expresses confidence and encouragement (verbal persuasion). While Goal-Setting Theory does not have a physiological arousal component, this

informational cue is the least influential for self-efficacy, so the other three main components are emphasized instead.

As the individual acquires these informational cues, Social Cognitive Theory proposes that self-regulative processes help determine whether the cues will influence self-efficacy. Through self-reflection and self-observation, the individual evaluates the information they have which informs and motivates their future behavior (Schunk, 1990). This process is aided by reflection because it provides observations that are normally subject to selective memory biases (Mace, Belfiore, & Shea, 1989). Reflection on past experiences generates more detailed information with which to inform beliefs and future behavior. More recently, this process of evaluating the four information cues has been elaborated by Gist and Mitchell (1992). Gist and Mitchell describe three main assessment processes which are used to determine how information cues will influence self-efficacy:

1. Analysis of Task Requirements. This is a determination of what it will take to perform a task.
2. Attributional Analysis. This is an analysis of why past behavior might have occurred and what caused it. For instance, if an individual excels in a presentation, he may attribute the success to his own skills and achievement or instead to the audience being unusually forgiving.
3. Assessment of Personal or Situational Resources. This is a consideration of personal and situational factors that might affect performance such as anxiety level or competing demands.

Of these three assessment processes, the most influential and highly researched is Attributional Analysis because it relates to other psychological concepts such as Locus of

Control. A person might be provided with a large amount of success information from Enactive Mastery, but if they discount the importance of the experience, and attribute their successes to external factors (rather than their own credit), self-efficacy will be uninfluenced. Thus in order to increase self-efficacy, the person must be provided with enough informational cues from Bandura's four sources, and these cues must be processed and attributed to accurate sources. Gist and Mitchell suggest that the best way to accomplish accurate attribution is to increase the person's understanding of the external and internal sources of the behavior. Using the example above, if the person can better understand the environment where they did their presentation, the complexity of the task, the strategies they used, the effort and motivation they put in, and the skills they possess, then the person is more likely to attribute his success to accurate sources that will likely raise his self-efficacy.

Autobiographical Memory and Self-Efficacy Theory. Self-efficacy theory describes four informational cues and subsequent assessment of these cues. Reminiscence and reflection may provide useful methods for increasing self-efficacy through both of these mechanisms. Enactive mastery is the most important information cue and one that naturally is supported through reminiscence on past behavioral successes. By revisiting the progress made toward achieving a goal or behavior, the person is consistently reminded of salient success experiences which should increase their belief in their capabilities. Through reminiscence, seeing is believing, and believing is a strong motivator for behavior change. In other words being reminded about past examples of successes might provide motivations to maintain those behaviors. Also, since reflection is physiologically identical to exposure therapy, it's possible that self-efficacy might also be increased by exposing oneself to past failures through emotional writing (Sloan & Marx, 2004). For example, if I have a fear of public speaking because of a

particularly embarrassing speaking engagement, the negative impact of this event might be reduced if I expose myself to the experience by writing. In other words, habituating to the trauma may reduce its negative impact on self-efficacy, further encouraging behavior change, by for example identifying extenuating circumstances associated with that specific experience. The potential for reflection to resolve self-discrepancies by re-appraising memories may also contribute to self-efficacy as failures find redemption in one's life story (McAdams et al., 2001). Additionally, reflective technologies provide opportunities for self-directed verbal persuasion and increased self-efficacy, which we discuss later.

Aside from providing informational cues, reflection can also aid self-regulation and attribution processes. As already noted, reflection increases insight which may help individuals become more accurate in attributional analysis. Since the accuracy of attributions is improved through understanding of internal and external determinants of behavior, the evaluative nature of reflection may help identify and clarify such sources.

Through the lens of self-efficacy theory we begin to see more clearly why the success of our behaviors depends on the function of our autobiographical memories. By remembering success experiences, we become more confident in our abilities - which inspires us to achieve new goals. This also helps explain why the working self is driven by self-enhancement motives because this bias toward optimism informs our self-efficacy and subsequent achievements.

Transtheoretical Model

While the Transtheoretical Model (TTM) is quite different from the previously discussed theories, we include it in this paper because of its popularity not just in health interventions, but also in designing tailored technologies for health interventions. It adds a temporal component that is lacking in the previous models. Using Goal-Setting Theory as an example, if an individual

doesn't find the behavior to be important, would it be optimal to provide an incentive and then apply social commitment? Or should the order be reversed if it even matters at all? The TTM provides information not only about *when* interventions should be delivered, but also about the *stages* the individual progresses through in their readiness to perform the behavior. The TTM was designed primarily to address addictions and inform treatment options for individuals but has been applied to both acquisition behaviors (like exercise) and extinction behaviors (like smoking) (Bridle et al., 2005). It is most often researched in the context of smoking and exercise, though recently has been applied to a wide variety of different behaviors (Glanz, Rimer, & Viswanath, 2008).

In contrast to the other models, the TTM was designed by James Prochaska to be an intervention based model not a predictive model (Prochaska & DiClemente, 1994). In general, the theory is weak at predicting whether individuals will perform the given behavior, but the focus is instead on which interventions to apply based on the individual. Because of this, there are strong proponents for TTM who are attracted to the tailored approach, while there are also strong critics who claim that the theory simply doesn't hold up well from a quantitative perspective (Sutton, 2001, 2005; West, 2005). The core construct of the TTM is the *stages of change* an individual progresses through as they become ready to perform the given behavior. These stages and their definitions are:

- Precontemplation. No intention to take action in next 6 months.
- Contemplation. Intends to take action in next 6 months.
- Preparation. Intends to take action within next 30 days.
- Action. Has changed overt behavior for less than 6 months.
- Maintenance. Has changed overt behavior for more than 6 months.

- Termination: No temptation to relapse and 100% confidence that they will not.

While many researchers mistakenly employ only the stages of change construct to their research, Prochaska has emphasized that there are three more important components (Glanz et al., 2008). These components are strategies that can help people progress through the stages of change. The first strategy is called *processes of change* which is a list of 10 activities people use at different stages to help progress to the next stage. These include interventions such as *consciousness raising* (learning new information to support the healthy behavior), *dramatic relief* (experiencing negative emotions that occur with the unhealthy behavior), and *helping relationships* (social support for behavior change). Each process of change is maximally effective when applied during specific stages, and can be even detrimental if introduced in inappropriate stages. For instance, interventions that help raise self-awareness and target internal factors are more effective in the earlier stages of change. External, environmental (such as reducing triggers), and relationship interventions are more effective in later stages.

The other two strategies are *decisional balance*, which is weighing the pros and cons of changing, and *self-efficacy*, which is defined here as confidence in one's ability to cope without relapsing. One of the limitations with the TTM is that the stages are arbitrarily defined. Practically, it seems unnecessarily rigid to say that a person who intends to take action within the next 30 days is in the preparation stage, while a person who intends to take action in the next 31 days is in the contemplation stage. Furthermore, like the other behavior change theories discussed this model is based on conscious awareness, such as contemplating the behavior and weighing pros and cons. As said before, addictions and habits often have an unconscious component that would seem to be outside the scope of TTM (Sutton, 2001; West, 2005).

Autobiographical Memory and the Transtheoretical Model. Reflection provides a method to deliver some of the interventions described in the processes of change to help people advance through the stages of change. Many of these interventions rely on increasing awareness about the behavior and its affect on self and others (such as consciousness raising). The evaluative, causal-reasoning attributes of reflection may be useful in this context, although these internally directed interventions are only useful at earlier stages (specifically precontemplation and contemplation). Thus reflection may not be as useful in later stages of change (such as when a person is maintaining their desired behavior) because external interventions are more appropriate at this time (like *helping relationships*). Additionally, reflection has potential to support decisional balance through evaluating pros and cons, and we have already discussed the potential for reflection and reminiscence to increase self-efficacy.

Summing up the Reminiscence and Reflection Potential for Behavior Change

As we have stepped through the most popular behavior change theories, we have seen how each relates to the others and provides new contributions to our conceptual map. While doing so, we have identified the most important mechanisms for change in each model, and we have proposed ways in which reminiscence and reflection are poised to support these mechanisms. In summary, reminiscence and reflection may aid behavior change by facilitating:

- The savoring of successes and reframing of failures help shift the SMS back from realism to optimism.
- The resolving of self-discrepancies that reduce motivation (i.e. rumination).
- Intrinsic feedback and enactive mastery (training, role-modeling) for increased self-efficacy.

- Insight and causal reasoning for more accurate attribution of success sources, also increasing self-efficacy.
- Identification of skills that lead to change, increasing Learning Goal Orientation and motivation.
- Increased self-understanding to identify less salient beliefs and motivations that might disrupt the unconscious cycle of habits.
- Intervention processes that accelerate one's readiness to change their behavior.
- Active evaluation of the pros and cons of changing one's behavior

Next we explore some of the technologies that have been developed to apply autobiographical memory and behavior change theories to real-world settings in a structured and practical format.

Memory and Behavior Change Technologies

At the core of this paper is the premise that autobiographical memory affects our ability to be successful in our behaviors. We've also seen how reminiscence and reflection might be useful tools to help support behavior change, for instance by gleaning insight and understanding from our pasts to inform our future behaviors. These memory processes may increase self-efficacy, allow more accurate source attributions, and support the directive function of autobiographical memory (Bluck et al., 2005; Taylor & Brown, 1988). However, because memory is fallible, reconstructive, and shows various biases (Bartlett & Burt, 1933; Burgess, 1996; Loftus et al., 1978; Schacter, 1999) this practice of analyzing and learning from our pasts is limited, because we do not have access to all the information we may need to gain deep understanding and change. For instance, if I get in an argument and use reflection to try and understand the causes and what I can learn from it, my analysis can only go so far as the data I can access (the details I remember), which may be subject to forgetting and self enhancement

biases (Conway & Pleydell-Pearce, 2000; Taylor & Brown, 1988). Furthermore, while reminiscence may help emphasize success experiences to increase self-efficacy, if my working self is completely grounded in the evidence of failure, I may not have access to memories of success that I can savor (Conway & Pleydell-Pearce, 2000).

One approach to addressing these memory limitations has been to employ technology to provide accurate information from the past (Berry et al., 2007). Because technology can provide access to the source details of events, this approach has been explored as a way to improve upon unmediated reflection and reminiscence, and to facilitate greater changes in behavior (Isaacs et al., 2013; Parks et al., 2012; Peesapati et al., 2010; Rich, Lamola, Gordon, & Chalfen, 2000).

One early approach was using digital tools to automatically *capture* as much information about an event as possible. This attempt at 'total capture' is called *lifelogging*. While lifelogging allows autobiographical events to be recorded with great detail, one criticism of these systems is that they overgenerate information as minutiae and useless details are captured. Veridical information of the past captured through lifelogging, cannot support self-understanding if relevant information cannot be retrieved for analysis. To correct this limitation, *personal informatics* aims to collect personally relevant information (as opposed to everything possible) for later review. Another goal of such systems is to use past information to promote behavior change.

There are two types of personal informatics systems: *event-specific systems* and *extraction systems*. Event-specific systems capture information from personally relevant events and send them back to the user for reflection or reminiscence. For instance, this can be done through simple digital photographs and videos, or more complex applications that collect multiple aspects of events for robust reflection (Isaacs et al., 2013). Lifelogging technologies are

not event-specific systems because they do not attempt to select among the vast number of events that they record (Whittaker et al., 2012).

Extraction systems identify information from our lives about which we often have little awareness. Rather than providing users with a veridical account of events (like event-specific systems), extraction systems analyze general information from our past actions for the purposes of changing these behaviors. A simple example of this is a pedometer which counts the number of steps a person takes. Information about personal step count is normally inaccessible through memory, but technology can extract this information from user routines. The goal of extraction systems is to support self-monitoring to provide awareness of behaviors (e.g. you have taken 4000 steps today). An application of this self-monitoring data is to provide information relevant to personal goals so that a user can both see where they currently stand, and where they aim to go (e.g. you have taken 4000 steps today and need another 1000 to reach your goal). To accomplish this, extraction systems use different goal-setting procedures such as *predetermined goals* (that do not change once they have been assigned), and *adaptive goals* (that adjust to the individual dynamically).

Total Capture: Digital Hoarding Through Lifelogging.

Imagine a future where we could capture everything that we see, touch, and do. We would forget nothing, and our fallible, natural memories would be replaced by prosthetic digital memories. We'd forget no names, no appointments, nothing that we had previously learned. We'd never get in arguments that question our actions because we'd have accurate records to review and resolve our disputes. This is the vision of lifelogging (also called "quantified self", "life caching", "self-tracking", "auto analytics" etc.), which is an attempt to digitally capture every bit of information we touch, and every event we experience.

Lifelogging began with Vannevar Bush's 1945 article "As We May Think" (Bush, 1945). In the article, Bush describes his vision of a system called Memex, a digital desk that stores books, articles, music, photos, and videos. By scanning these materials, Memex would digitally capture each of these objects in entirety to be accessed as needed. Later the abstract descriptions of Memex served as a blueprint to build real lifelogging systems such as MyLifeBits (Gemmell, Bell, Lueder, Drucker, & Wong, 2002). MyLifeBits was an attempt to fulfill Bush's vision, first to support the scanning and storage of documents, music, and other objects, and then to explore capturing activities as well. For instance, MyLifeBits has the capacity to record web pages visited, phone calls, meetings, conversations, keystrokes, and mouse clicks (although capturing these activities often requires time-consuming effort from the user) (Gemmell et al., 2002). Video and audio have also been included, as well as capturing of still pictures with Microsoft's SenseCam (Hodges et al., 2006). Sensecam captures images triggered by movement and changes in heat and light, generating thousands of images of personal activities each day. Work on lifelogging goes back many years, with early systems built during the 1990s (Mann, 1997; Newman, Eldridge, & Lamming, 1991; Whittaker, Frohlich, & Daly-Jones, 1994). More recent examples of lifelogging systems are Ubiqlog, which uses mobile phone sensors for continuous capture, Narrative Clip (formerly Memoto, a small wearable microcamera that takes pictures every 30 seconds, and Google Glass, which is wearable glasses with a built in camera to allow video, audio, and picture capture (as well as other augmented reality features).

While the vision of recording all the details of one's life seems to promise 'total recall', there are three fundamental flaws with lifelogging systems that Sellen and Whittaker (2010) have identified: (1) Their usefulness is limited for remembering our pasts, (2) they have not been

embraced for widespread use, and (3) they are not built to support natural memory functions. We explain each flaw in detail below.

First, studies on lifelogging systems don't tell a very impressive story about their usefulness in promoting recall. For instance, Kalnikaite, Sellen, Whittaker, and Kirk (2010) assessed memory for daily events in a group that used a lifelogging system for two weeks as compared to an unmediated control group. They found that even though lifelogs generated a rich record of everyday events, users were unable to navigate these to find important or significant images. And when asked to recall their everyday activities, the lifelogging group performed no better than the control group who didn't use technology. Similarly, Sellen et al. (2007) found small benefits of lifelogs for long-term memory.

And because lifelogging overgenerates digital records for rich archival storage, people often do not access this mass of information. Petrelli and Whittaker (2010) investigated digital memorabilia (such as email, photos, videos, and scanned images) and found that people rarely access these records. Also, Whittaker, Bergman, and Clough (2010) showed that people with large collections of digital photographs never access the vast majority of them. It seems that in practical contexts, a mass storage approach for digital archives may not be a very useful technique for remembering our pasts. This is supported anecdotally by Gemmell, Bell, and Lueder (2006) who describe MyLifeBits as a black hole that stores an overwhelming amount of information, where everything goes in and nothing comes back out.

Secondly, despite their intuitive appeal, very few lifelogging systems are in everyday use (Sellen & Whittaker, 2010). Since Bush's 1945 Memex vision, different research labs have attempted to build working lifelog systems but these systems have not been adopted on a wide scale. For example early versions of lifelogging systems were developed in research labs in the

early 1990s but none have reached the mass market. Only a few lifelogging extremists (such as Steve Mann and Gordon Bell) persisted with the idea of capturing as much of their lives as possible (Bell & Gemmell, 2009; Mann, 1997). The simple fact that these systems have struggled to find popular interest seems to reflect their failure to practically help us remember our pasts.

Lastly, lifelogging systems don't discriminate which data might be valuable to the user, nor are they designed to address specific memory functions. Reminiscent of a digital version of hoarding, the emphasis is in knowing that you have captured everything in case something might come in handy at some future time. Sellen and Whittaker (2010) argue that these systems need to be designed to support the aspects of human memory that actually need supporting, rather than haphazard total capture. As we will now see new systems have been developed to address clear memory issues that we have previously discussed (such as gaining access to the source information of memories for enhanced reminiscence and reflection). These new systems emphasize both the capturing of personally relevant events, and later retrieval of these records to facilitate learning from our pasts and behavior change. These systems are part of an emerging field called "personal informatics," where in contrast to lifelogging, there are demonstrable benefits to technology deployment.

Capture and Retrieval: Personal Informatics for Self-Knowledge and Change

The term *personal informatics* was first coined by Ian Li to describe a growing class of systems that were being developed to improve upon lifelogging (Li, Dey, & Forlizzi, 2010). While lifelogging attempts to capture as much information about one's life as possible, personal informatics focuses on capturing personally relevant information with the express intention of retrieving this information later. In other words, this information is *about* and *for* the person. By

capturing veridical records and facilitating subsequent retrieval of these records, personal informatics systems could be powerful tools to help reminiscence, reflection and behavior change. In this review, we categorize personal informatics systems as either event-specific systems or extraction systems. At the end, we propose a new class of hybrid systems that bridges the key strengths of both classifications.

Event-Specific Systems. Technologies that facilitate reminiscence and reflection are typically event-specific systems, while those that facilitate behavior change tend to be *extraction* systems. Event-specific systems allow for reminiscence and reflection on the actual recorded event details, rather than the memory of the event as occurs when unaided by technology.

Technology Mediated Reminiscence. As described earlier, unmediated reminiscence is the process of remembering autobiographical memories. It differs from reflection in that reminiscence does not contain in-depth analysis or evaluation of these memories. Similarly, reminiscence systems facilitate remembering of autobiographical memories, but they also enhance this process by veridically capturing events. They provide detailed records of past events for more accurate and comprehensive reminiscence.

Unlike lifelogging systems that are not designed with clear memory objectives, reminiscence systems are built to improve memory or increase benefits that are naturally obtained through reminiscence. SenseCam is an interesting example of a system that was originally built for lifelogging, but can be useful when employed for reminiscence with Alzheimer's patients who typically have difficulties with establishing new autobiographical memories. One common recommendation for these patients is that they generate diaries of everyday events. However, Hodges et al. (2006) demonstrated that SenseCam was about twice as effective at helping Alzheimer's patients remember events as traditional diary methods.

Furthermore, Berry et al. (2007) showed that traditional diary methods were not only less effective, they were more onerous and had lower rates of compliance than the automatic capture provided by SenseCam. While SenseCam as a lifelogging system without clear memory objectives has been shown to be problematic at improving memory for normal populations (Kalnikaite et al., 2010; Sellen et al., 2007; Whittaker et al., 2012), it becomes useful when focused at those with specific memory conditions.

Unmediated reminiscence also encourages savoring and increased well-being when remembering positive past events (Bryant et al., 2005; Wildschut et al., 2006), so other systems have been developed specifically for these purposes in non-clinical populations. For example, the iPhone application, Live Happy asks users to keep a "savoring photo album" and to "remember happy days" by reviewing emotionally positive pictures of personal events. While users are given the opportunity to write about these positive pictures (similar to reflection), they are not asked to *analyze* the experience, instead to register and savor positive feelings associated with it. Because they do not evaluate the events, and only remember and register them, this is an example of a reminiscence system.

In a study where 2928 participants used the application, participants increased their scores on standard happiness surveys after using the system for 3 to 14 days (although this sample was not controlled nor randomly assigned) (Parks et al., 2012). Other examples of reminiscence systems are Remind.me, 1 Second Everyday, MorningPics, Timehop, and Everyday.me. Additionally, because natural reminiscence often takes place in a social context (Cohen & Taylor, 1998), some systems have explored social reminiscence. PosiPost Me gives users an opportunity to share and express positive experiences with their friends, any time and any place from a mobile phone. Other reminiscence systems with a social component are

Moodmill, Mobimood, SharePic, CaraClock, and eMoto. However, these systems have not been evaluated systematically.

Technology Mediated Reflection. Very few studies have investigated the potential for reflective systems. The first study of its kind was conducted by Peesapati et al. (2010) with a system called Pensieve. Pensieve (which sounds like the word "pensive" and connotes deep reflective analysis) presented users with Facebook posts they had previously created. This system encouraged reflection because users were asked to analyze their posts and wrote their thoughts in a personal online diary. A researcher-developed questionnaire revealed that participants found the process to improve their mood and support other benefits of reflection such as self-understanding and perspective-taking (Peesapati et al., 2010). Furthermore, the researchers analyzed the content of reflections by counting the percentage of words that fall into specific linguistic categories. They found that reflections contained words about the past and the present but few words about the future. They concluded that people used Pensieve to "make terms with their pasts and apply it to present day problems" (Peesapati et al., 2010, pg 2030).

While Pensieve facilitated reflection, the targets of the reflective writing were the initial Facebook posts which captured events, but these posts were *not designed with later reflection in mind*. In other words, Pensieve chose captured events that were created independently and not with the intention of later reflecting on these records. To address this, Isaacs et al. (2013) designed Echo. In contrast to Pensieve, users generated recordings that were written with the future in mind, knowing that reflections would be written about those events later. The researchers found that capturing roughly three events per day for one month, and reflecting on these events at varying lengths of time, significantly increased participant well-being. Echo also

facilitated other classic benefits of reflection such as the construction of redemption sequences, increased cognitive and insight words in reflections, and perspective-taking (Isaacs et al., 2013).

Similar to Pensieve, the Echo researchers measured the percentage of words in specific linguistic categories, but they also correlated these percentages with changes in well-being. Initial Echo posts containing words about the present and the future were significantly correlated with improved well-being. The researchers concluded that it was adaptive to "prescribe future lessons from present understandings" (Isaacs et al., 2013, pg 1077). Thus while Pensieve illustrates how technology might help people make sense of their past (i.e. past and present word usage), Echo shows us that reflective technologies can be beneficial not only retrospectively but prospectively, by capturing events with future reflection in mind. And while neither study investigated behavior change, these findings show a manifestation of the directive function of autobiographical memory (to guide future behaviors from past behaviors). The results suggest that this natural function of unaided memory might be bolstered by reflective systems that give us the power to control both the capturing and the reflecting on events. Lastly, another tangible way reflective systems could impact behavior is through *communication* (Goal-Setting Theory) or *verbal persuasion* (Self-Efficacy Theory) to express confidence and encouragement for increased self-efficacy. Users could embed words of encouragement into their initial posts to be reflected on later, effectively communicating with their future selves.

Extraction Systems. As we've seen, event-specific systems capture *veridical* information about personal *events* for reminiscence and reflection. Another approach to personal informatics is to *abstract* information from *activities*, with the purpose of self-monitoring aspects of behavior of which we're not normally aware, to promote insights into those behaviors. They aim to provide a different type of support for unaided human memory by providing monitoring

and abstraction; without such technology people find it hard to continuously track and remember activities over long time intervals, and draw inferences about specific habits. (Li, 2012)

Examples of extraction systems are simple pedometers that track step count, or more complex systems like the Bodymedia SenseWear armband that monitors body acceleration, step count, skin conductance and skin temperature (to calculate calories burned). To promote insights about behavior from these low level data, this more complex system provides visualizations to help teach the user about their energy expenditure, sleep quality, and other important health factors. By tracking multiple streams of health information and then packaging that information into an interpretable format, people learn about themselves in ways that might guide their behavior. Other examples of extraction systems are Wellness Diary, which records factors such as sleep, stress, and mood, and Runkeeper, which records running and cycling activities. Both systems chart the data they collect to help users identify trends.

These types of self-monitoring extraction systems assume that simple awareness of activities itself inspires behavior change (Klasnja & Pratt, 2012; Li, 2012). This is supported by behavior change theory showing that self-monitoring increases awareness of success experiences (increasing self-efficacy and performance), fosters self-insight which can help a person make better decisions, and inspires behavior change (Endsley, 1997; Gist, 1987; Kopp, 1988; Mace & Kratochwill, 1988). Demonstrating this empirically, Kollmann and colleagues (2007) designed and evaluated a system called Diab-Memory to help diabetics monitor blood glucose, activity levels, insulin use, and carbohydrate consumption. Using the system over three months helped participants identify factors that affected their diabetes, and in turn this lowered their blood glucose and HbA1c levels.

We've also seen in the behavior change section of this paper that self-monitoring can be useful to help generate goal-achievement strategies (i.e. Learning Goal Orientation). However, it can be detrimental if people generate inappropriate strategies without the guidance of external feedback (Anseel et al., 2009; Gist, 1987). For example, if I have a goal of increasing my fitness, and I learn from an extraction system that I walked 4000 steps today, should my strategy be to walk 5000 steps tomorrow, or 8,000 steps? Given my previous performance, is 8,000 steps reasonable or am I setting myself up for failure? This is an obstacle for extraction systems because people aren't always clear on what the next step is to reach their goals once they're received their extracted data (Li, 2012). External feedback is helpful in this context to help keep the user on track and guide them toward appropriate solutions (Anseel et al., 2009). Some extraction systems approach this problem by evaluating users' progress against clear personalized goals. These systems can be categorized by their goal-selection strategies which are either predetermined or adaptive.

Predetermined strategies profile the user along different dimensions to set goals. These goals remain fixed, and extraction systems provide data that suggests progress against those goals. For instance, systems like Chick Clique, Houston, and Ubifit set personalized goals for each user but these are not continually reevaluated and readjusted as the user progresses (Consolvo, Everitt, Smith, & Landay, 2006; Consolvo et al., 2009; Toscos, Faber, An, & Gandhi, 2006). Another example is the Mobile Lifestyle Coach where users earn "lifestyle points" for exercising and eating healthily. Users attempt to earn the same predetermined number of lifestyle points each day (Gasser et al., 2006). While systems that use predetermined strategies and goals are simpler to develop, behavior change theories would suggest that they are disadvantageous in certain scenarios. For instance, if the user surpasses a goal, they may lose motivation (goal-

setting theory), or if goals are too difficult users might lose self-efficacy (self-efficacy theory). Adaptive systems attempt to avoid these scenarios by extracting information and evaluating this against goals that adjust to the user's progress.

Adaptive systems are more complex because they oftentimes rely on professionals to evaluate progress and set new personalized goals. For example, Farmer et al., Kim and Kim, and Walters et al. describe systems that afford logging of health information that is continually reviewed by a nurse or healthcare practitioner who provides feedback and adjusts goals (Farmer et al., 2005; Kim & Kim, 2008; Walters et al., 2010). Automated approaches that don't rely on professionals are less common but are rapidly becoming popular, because they potentially address health problems in a low cost manner. Examples of such systems are Fish'n'Steps, SMS Coach, eMate, and Bickmore's relational agent interface ("Laura"), which assess disposition and user performance to tailor appropriate goals (Bickmore et al., 2005; Haug et al., 2009; M. Klein, Mogles, & van Wissen, 2013; Lin et al., 2006). SMS Coach is an interesting example because adaptive goals are determined to help users *reduce* an undesired behavior, by quitting smoking, whereas most systems try to *promote* a desired behavior such as physical activity. In SMS Coach, users complete weekly surveys on their phone that assess how much they are smoking and their readiness to quit based off the Transtheoretical Model. This dynamic information is combined with baseline information such as their smoking history, and reasons for smoking, to customize educational and motivational messages that are sent to the user three times per week. Although the intervention was based off behavior change theory (TTM) and delivered adaptive goals, the study did not find reductions in smoking from using the system. However, user acceptance of SMS Coach and continued use of the system was observed across a three month

study (only 3 dropouts out of 110 participants) which suggests that this approach might be useful for tailoring more efficacious interventions (Haug et al., 2009).

While the vast majority of extraction systems are not based on behavior change theory, even those that are tend to address some components of the theory while ignoring others (Riley et al., 2011), For instance, Ubifit was based on Goal-Setting Theory because goals are selected to be difficult and specific, but other components like *commitment, importance,* and *complexity* were largely ignored (Consolvo et al., 2009). Other extraction systems are said to be based on multiple theories at once, while the specifics of how these theories informed their design are never discussed (Hurling et al., 2007). In a review of 49 studies of theory-based behavior change systems, none evaluated the theoretical components hypothesized to be influenced by the system (they instead measured outcome behaviors like step count). In other words, these systems might have been designed by theory, but it is unclear whether they practically operate according to theory (Riley et al., 2011).

Personal informatics supports autobiographical memory with event-specific systems to promote reminiscence and reflection, and behavior change with extraction systems that support self-monitoring. However, none of these systems consider both memory *and* behavior change. That is to say, theory-based event-specific systems are typically built by memory theorists to solve memory problems (Parks et al., 2012; Peesapati et al., 2010), and theory-based extraction systems use behavior change theories to inspire change (Consolvo et al., 2009; Haug et al., 2009). As we've seen in this paper, there is overlap between memory and behavior change theories because our ability to monitor and analyze our past behaviors depends on memory. Therefore, there is potential to develop hybrid systems that consider both memory and behavior change approaches. For example, a system that employs extraction techniques might provide

new advantages for reflection not currently employed by event-specific systems. Extraction techniques could help visualize past events and display trends for further self-knowledge that are not supported in current event-specific systems. Someone who experiences fear when they speak publically might be able to see through extraction and reflection that these experiences tend to work out well. Knowing that they tend to succeed regardless of how they feel before they speak might put them at ease. This type of learning would not be available to the person using strict event-specific systems that don't abstract across repeated events.

Alternatively, a system that employs event-specific techniques might provide new advantages for behavior change. Because event-specific systems support reflection and reminiscence, they may also help encourage behavior change through features of these processes that follow from better understanding of specific success and failure cases (such as increased learning-goal orientation, more accurate source attributions, enactive mastery of success experiences, habituation and re-appraisal of failures, and self-efficacy) (Bandura, 1977; Bryant & Veroff, 2007; Gist & Mitchell, 1992; Locke & Latham, 2006; McAdams et al., 2001; Sloan & Marx, 2004). Extraction systems currently do not support analysis of specific past events to guide future behaviors. Thus a hybrid system could engage the methods of one class of system (event-specific techniques) for the objectives of another class of system (behavior change). We are aware of only one study that has employed event-specific techniques to support memory for behavior change purposes. Rich et al. (2000) had asthma patients videotape and reflect on their daily lives. By accurately documenting the moments of their lives and then reflecting on these, patients became more aware of the presence of allergens in their routines that impacted their health. Rather than extracting information like systems typically designed for behavior change, the videotapes facilitated veridical capture of events for later analysis. The authors conclude that

video reflection gave participants new perspective and distancing from their routines to gain insight into their behaviors. As a result, their asthma-specific quality of life was significantly improved (as measured by standard survey instruments). This preliminary study lends support for the potential of a hybrid system to provide new insights about our lives, and deeper consideration of memory processes that affect our behaviors.

Conclusion

By reviewing the main theories of autobiographical memory, behavior change, and technologies that address both, we have identified new connections that improve our understanding of each. We've shown that autobiographical memory is more than just memory of past personal events. It is fundamentally a goal-driven process to enhance the positivity of our memories and guide our behaviors (Conway & Pleydell-Pearce, 2000). We have described three examples that override memory self-enhancement, such as overwhelming evidence of failure (shifting the SMS from optimism to realism), PTSD (triggering intrusive memories of event-specific knowledge), and rumination (overgeneralizing focus on symptoms). We have shown that reflection and reminiscence are tools that can support self-enhancement through savoring of positive events and transforming negative events to more positive evaluations (Bryant et al., 2005; Pennebaker & Chung, 2007). However, current research has not yet answered *when* these interventions should be applied, or precisely *how* these interventions work. While the Transtheoretical Model offers a temporal description of when reflection and reminiscence might be most effective (e.g. during earlier stages of the model), it does not consider the temporal dynamics of memory. The TTM addresses the individual's readiness for change, but does not speak to the time course of failed self-enhancement motives. Should we give a reminiscence intervention before the SMS shifts from optimism to realism or after it has experienced evidence

of failure? Should we give emotional writing interventions directly after trauma experiences or should we let natural grieving processes run their course first?

There is also much work to be done to address how reflection and reminiscence leads to health and behavioral benefits. For instance, we have discussed the self-awareness qualities of reflection but when these properties are isolated in experimental manipulations, participants don't benefit more than controls (Seih et al., 2011; Stanton et al., 2002). Thus, the properties of reflection and reminiscence we have explored in this paper might be emergent side-effects of more fundamental, currently unidentified mechanisms.

We've also seen how reminiscence and reflection can influence behavior as we've stepped through the main models of behavior change. However, the reader might be left wondering which model is considered the gold-standard and which one they might consider adopting for their research purposes. For instance, we may think that Goal-Setting Theory is more thorough than the other theories but then find it difficult to design practical interventions that address each of its many components. Thus, we might favor the parsimony of the Theory of Planned Behavior, but have trouble deciding which survey instruments to utilize because there are currently no best-practice recommendations for measuring the model components (Ajzen, 2002). And if we choose the simplicity of Self-Efficacy Theory (or the temporal advantages of the Transtheoretical Model), we may miss critical factors such as *attitude toward the behavior* that could render our interventions useless.

There is currently no consensus of which behavior change models are most appropriate in which contexts. Meta-analyses have attempted to identify the types of behaviors that each model might be best suited for changing independently (Hardeman et al., 2002; Mento et al., 1987; Prochaska, 1994), but a taxonomy across these four major theories has not been established.

Rather than seeking a holy grail for behavior change models, we must consider the diversity of behavior, and empower researchers with knowledge of which theories are best suited for the behaviors they are interested in. Additionally, since none of these major behavior change theories address unconscious aspects of behavior (that might influence habits and addictions), there is room for new models or amendments to current models. Technology might provide advantages in this area since extraction systems are designed to increase awareness of unconscious aspects of behavior. These systems might serve as the missing link between current theories and the unconscious behaviors they fail to address.

Finally, while personal informatics improves upon lifelogging by capturing personally relevant information as opposed to "total capture", there is still room for further refinement. As it stands, extraction systems might present new information about behaviors that people were not aware of, without considering whether this is adaptive in the first place. While step count might be considered "personally relevant" information, learning that I walked less than my goal might contradict self-enhancement biases of memory that are adaptive for behavior. Furthermore, extraction systems currently fail to provide recommendations about how to act on the information that they provide. How should my behavior change now that I know I walked less than I intended?

We've also seen how event-specific systems can facilitate savoring of positive memories (reminiscence systems), and transformation of traumas (reflection systems), but these systems largely don't explore how more neutral events might impact their users. Systems like Echo and Pensieve don't discriminate between events for reflection so that the whole spectrum of emotional valence is revisited (Isaacs et al., 2013; Peesapati et al., 2010). Is it adaptive to reflect on mild annoyances (as opposed to traumas) to transform these memories or will they override

self-enhancement biases? It might be more difficult to find redemption sequences in annoyances (such as stubbing your toe) than traumas (such as our soccer student example). We are currently running a study that explores reflecting on neutral versus emotionally extreme events to help us answer these questions.

Additionally, should reflective systems present traumas for analysis but withhold positive events since these have been shown to reduce well-being when under the analytical scrutiny of reflection (Lyubomirsky, Sousa, et al., 2006)? There is potential here for hybrid event-specific systems to facilitate reflection about traumas along with reminiscence on positive events (as theory might suggest is most adaptive). In summation, as all information is not useful in the context of lifelogging, all personally relevant information may not be adaptive in the context of personal informatics. Theory-based refinement of personal informatics is an important next step.

Finally, new hybrid systems unite the major sections of this paper by drawing on behavior change and memory theories and systems that apply these theories to real world problems. While we did not set off to develop ideas for hybrid systems, exploring connections between three seemingly unrelated fields revealed new potential for solving problems in one field by applying solutions from other fields. For example, behavior change systems might improve their effectiveness by considering the underlying influence of memory. It is our hope that this review will inspire both theorists and system designers alike to step outside their comfort zones to find new inspiration from these complementary fields.

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