Evaluating How the Organization, Connection, and Evolution of Prior Knowledge in Long-Term Memory Drives Top-Down Processing

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Humans often resist change, even when an innovation brings exceptional value and ease to their lives. We have evolved as rapid samplers who need to understand information and make fast decisions to survive, so we prefer relying on prior knowledge and experiences. Change is difficult because it requires time and energy to learn something new or modify an existing routine. Top-down processing describes the way humans perceive the world based on cognition. The human brain inserts meaning and connection based on what it already understands, has experienced, or expects. In other words, the concept of long-term memory (LTM) and prior knowledge drive top-down processing effectively allowing humans to name and store incoming stimuli. This review aims to explain how the human knowledge system, with infinite capacity, functions by explaining the way LTM and prior knowledge are highly organized, intricately interconnected, and constantly evolving. With a deep awareness of how the knowledge processing system operates, designers can leverage the information to create valued, intuitive, and accepted products and services. The remainder of the review will evaluate the Venmo app and how the concept has been adopted based on people's prior knowledge of money transfers.

3 Themes of LTM and Prior Knowledge Drive Top-Down Processing

Theorists share a consensus on how human memory operates. Norman (2013) describes after the information has moved through the pre-attentive stage and moves to working memory, it is ready to be stored in LTM when it has been paid extra attention or is referenced frequently. He elucidates that since LTM is so expansive with infinite capacity, it must be efficiently organized so the prior knowledge is readily available and easily retrievable. Brod et al. (2013) describes how prior knowledge impacts the cognitive processes vital to learning and retaining new information and converting it to memory. These cognitive processes "form the basis of semantic memory, which is factual knowledge about the world, and episodic memory, which is memory bound in time and place" (Tulving, 1972, as cited in Brod et al., 2013). Brod et al. explains how prior knowledge increases neural activity in the medial prefrontal cortex (mPFC) and hippocampus (HC) leading to increased comprehension, memory, and retrieval (2013). There are various theories proposed to describe the elaborate processes within human memory and how humans store and access knowledge.

Prior Knowledge is Highly Organized

Prior knowledge in LTM is named, structured, and highly organized in a set logical and rational place so it can later be retrieved in an efficient manner (Rumelhart, 2017). Among the most prominent memory organizational models is schema theory. This theory consists of *schemata,* originally proposed by Piaget (1926) and Bartlett (1932), which are powerful data structures that store concepts such as "objects, situations, events, [and] actions" in memory (Rumelhart & Ortony, 2017, pg. 101). They explain that as "the basic building blocks of human information-processing," schemata are vital to the knowledge comprehension and prediction process (pg. 112). When humans attempt to understand new information, schema theory proposes that schemata are selected to 'account for' the information being comprehended in a matching process (Rumelhart & Ortony, 2017). They explain this is similar to the scientific process of matching evidence to either confirm or reject a conclusion. If a reasonable fuzzy match is found, even if it is not perfect, the incoming information can be somewhat comprehended or lead to a prediction or inference. This occurs because it is similar to the schemata that exist in LTM (Rumelhart & Ortony, 2017).

Frame theory, rationalized by Minsky (1974), refers to *frames* as a type of schemata. Minsky describes frames as a "network of nodes and relations" with high-level concepts that are always valid about the situation and lower levels of many *slots or terminals* that can be filled with proposed concepts that may or may not validate the frame. Additionally, frame theory includes a matching process that attempts to "assign values to each frame's terminals" (Minsky, 1974). He notes if prior knowledge exists about a situation, some of the terminals in the frame will already be filled since it has similarities. However, there will be room to update the terminals about the specific situation which serves as a way to modify existing knowledge to learn new information.

Scripts are another type of schemata (Abelson, 1981) that hold representations of information about standard stereotyped sequences, tasks, and routines—such as how a typical restaurant ordering process works. As Abelson explains, without having to explicitly experience a stimulus, scripts allow humans to draw from prior knowledge and infer how a process is assumed to or usually plays out. Mental models are an additional powerful form of an organizational schema, originally proposed by Craik (1943), Johnson-Laird (2004, pg. 181) explains that a mental model "has the same structure as the situation that it represents." Humans form mental models of systems and processes they interact with in the natural world that guide their expectancies of how a system will function (Norman, 1983). When a mental model is tested and validated, it creates or modifies a schema that can later be drawn from. Norman suggests a designer's role is to create a system in which the user "acquires a mental model that matches the designer's conceptual model" which leads to deep learning, understanding, and comprehension of the system (pg. 3).

Barsalou (1991) discusses the concept of categorization as a way humans build hierarchical mental models. He explains, "the purpose of categorization is to identify information in memory that provides useful inferences." Thus, he describes categorization helps humans with knowledge comprehension because categories reveal information about the origin, structure, probable behavior, inferences, and more. Heit (1994) clarifies, "when people learn about a new category, they are influenced not only by observed members of this category but also by prior knowledge of other, related categories" proving that humans seek understanding by accessing similar schemas stored in LTM (pg. 1264). All of the proposed cognitive organizational models allow for a starting point at which humans can modify or build knowledge. Schemata do not exist in siloed parts; instead, schemata are powerful because of the interconnectedness within LTM.

Prior Knowledge is Intricately Interconnected

Humans do not store exact copies of past information and experiences in memory. New information is connected to and matched with prior knowledge in the vast network of LTM. This signals that the relationship between information matters most (Brod, 2013). Further, this means humans do not have to experience everything in exactness to find understanding because prior knowledge is interconnected. If designers have a solid understanding of the prior knowledge connections users will likely make in LTM, then products and services can be designed to leverage the likely connections leading to adoption and understanding. The interconnectedness of prior knowledge is explained through various network theories including semantic, propositional, and frame-system networks.

Within LTM, network theories are composed of nodes that represent separate concepts which are interconnected along linked paths through the spreading activation theory (ACT) (Anderson, 1976) (Collins & Quillian, 1969). ACT states that the recognition and comprehension of incoming information rely on the activation of the correct nodes that lead to the correct path in a network (Anderson, 1976). He clarifies that as more paths are available from each node, activation spread slows which is referred to as the "fan effect" describing how the paths fan out from the nodes. As paths are activated, the knowledge of each node becomes available for processing as the fan effect spreads activation throughout the neural network (Anderson and Pirolli, 1984).

A semantic network structure requires minimal memory storage and consists of nodes that point to other nodes in the hierarchical network that may either be supersets, subsets, or properties of the current node (Collins & Quillian, 1969). It is important to note semantic networks are not always clear, straight paths on a hierarchy though, and there is often repetition of nodes which is a point of issue with the theory. Similarly, propositional networks, made of encoded propositions which are "units of meaning that can take a truth value," are organized to show connections when propositions "share an argument" (McKoon & Ratcliff, 1980, pg. 369). Furthermore, frame-system networks also share similar qualities. Frames form networks because "different frames of a system share the same terminals" (Minsky, 1974). For example, frames are activated in networks "when evidence and expectations make it plausible that the scene in view will fit [the frame]" (Minsky, 1974). Each proposed network model displays the deep interconnectedness of prior knowledge in LTM, but the idea that prior knowledge is constantly evolving drives the ability of schema to build connections.

Prior Knowledge is Constantly Evolving

Humans are always experiencing new situations that modify, update, or change prior knowledge or create new knowledge schema in LTM. In other words, humans are constantly learning. Piaget (1969) discusses learning through the lens of creating an equilibrium in the mind, suggesting when the mind does not have equilibrium, confusion, and cognitive dissonance occurs.

He clarifies that all exchanges between the internal mental and biological factors and the external physical, social, and environmental factors are composed of either assimilation or accommodation. *Assimilation* is combining an external factor with the existing internal factors to slightly modify existing mental model schemata. Conversely, *accommodation* requires creating a new place for the external factors to fit with the existing internal mental models—i.e. learning and storing something new altogether (Piaget, 1969). Rumelhart and Norman's (1976) notion of learning is similar through the exploration of accretion, tuning, and restructuring. *Accretion* is the most common type, known as fact learning, that allows humans to expand on already existing schemata by accumulating and making sense of new information, this is reminiscent of Piaget's assimilation (Rumelhart & Norman, 1976, 1981). They explain *tuning* as the more difficult continual evolution of schemata to create deeper learning and develop the expertise to make the knowledge more congruent with new information. Last, *restructuring* is the most significant type explained as creating new schema structures, allowing for "new interpretations of knowledge" which requires a great deal of cognitive load and effort, similar to accommodation (Rumelhart & Norman, 1976, pg. 4). Accommodation and restructuring require so much effort because humans naturally resist change unless it delivers extreme value, thus it is easier to rely on assimilation and accretion because there is already a connection to something familiar.

The idea of connecting to something familiar in LTM making knowledge acquisition easier is why affordances, metaphors, and analogies are so helpful. Introduced by Gibson (1979), affordances show "possibilities for action" in interactions with the world by connecting to existing schemata (Adolph & Kretch, 2015). Norman (1999) makes a connection to the digital world and goes on to explain how affordances are powerful when the "user perceives that clicking on [an] object is a meaningful, useful action, with a known outcome." In terms of metaphors, familiar and relatable stories provide an entry point to prior knowledge that fosters an easier understanding of new knowledge (Hsu, 2006). Neale and Carroll (1997) explain how metaphors allow humans to map knowledge from a familiar and comfortable area to an unfamiliar area to make understanding new knowledge easier by leveraging an example from prior knowledge in LTM. Therefore, designers should consider how well the desired use of their products and services is perceived by users and consider developing metaphors and affordances to strengthen the desired usage.

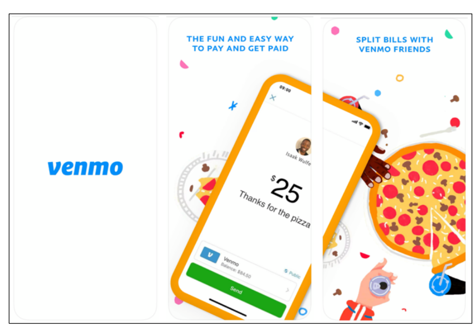

Figure 1 *– View of Venmo's logo and app store add signaling the purpose of Venmo: to pay and get paid and split bills with friends.*

Prior Knowledge Applied to Venmo Case Study

Venmo is an innovative digital wallet mobile app allowing US citizens to transfer money from peer to peer **(Figure 1).** This case study is considered through the lens of a user who has experienced traditionally transferring money through a physical banking company or an online banking system and may be reluctant to trust and adopt this tech innovation.

As someone attempts to understand the concept of Venmo, they would search for schemata in a semantic network in their LTM to ‘account for’ and activate possible paths to help them understand the idea of mobile app money transferring. The schemata could include mobile apps, online banking, physical banking, banking mobile apps, payments, credit cards, social networking, cash, wallets, and more. Drawing from any of the listed schemata would likely generate fuzzy matches, but nothing will match the exact knowledge that using Venmo requires. Because of this, the mind will fill in gaps and make connections to any schemata possible through the ACT fan effect. For example, users may draw from an existing script schema which includes an online banking process to transfer money. This script may require logging in to verify identification, choosing the right person by knowing the receiving party’s account number, asking for their account number if necessary, as well as being in the same banking network. Venmo does not use account numbers like traditional banking methods, instead, Venmo’s scannable QR code or a person’s username are metaphors to the traditional account number **(Figure 2).** This could lead to user error and frustration of sending funds to the wrong person by typing in the wrong username. Also, Venmo does not require users to be in the same banking network, so someone using a credit union in one state could transfer money from their account to someone with a different credit union or even someone using a big national bank elsewhere. The idea of transferring money to anybody in the country is Venmo’s innovation and ticket to disrupting the banking industry, but it does not directly align with an exact existing mental model of how money transferring usually works.

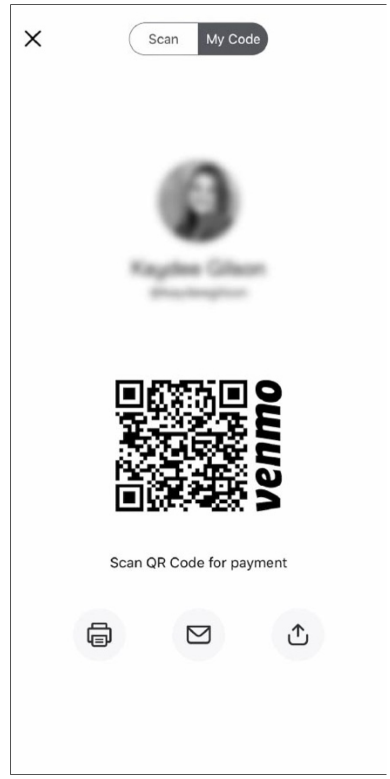

Figure 2 – *View of Venmo’s QR code and person’s username and photo that serve as metaphors for a traditional bank account number.*

Venmo is more easily adopted by younger generations who grew up with mobile apps and have developed a trust in online shopping, banking, and networking. For someone who grew up hesitant to trust the internet or grew up with parents or grandparents who were hesitant to trust big banks because of the Depression, Venmo may not portray the affordance of trust and security. Venmo’s social networking and stored balance piece **(Figure 3 & 4)** often confuse more mature generations because their mental model of banking and security does not include the idea of social media and transactions possibly being public knowledge or trusting a new company with securely storing their money. The stored balance piece is an analogy of the traditional bank account which may help assimilate the new idea with the existing banking schemata. Venmo also uses icons such as locks to portray security. Overall, Venmo requires people to adopt a version of accommodation and restructuring to build a new schemata structure to use and comprehend the app.

Conclusion

To conclude, human memory is a powerful network of highly organized, structured, and evolving knowledge that humans can leverage to make quick and reliable decisions. Top-down processing is driven by intricate cognitive processes of prior knowledge such as mental models, networks, and spreading activation. These cognitive processes teach designers the importance of mirroring prior knowledge and experiences to 'meet people where they are at' to create new technology of high value that will be intuitive, trusted, and adopted.

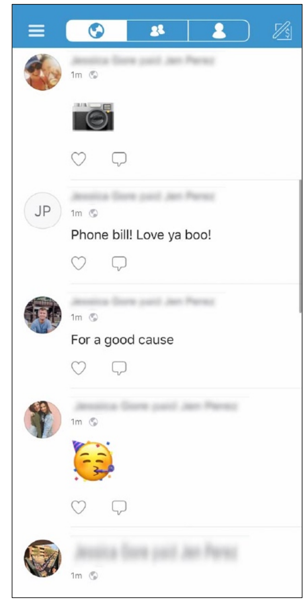

***Figure 3 –** View of public transaction descriptions that resembles social networking sites with like and comment buttons, emojis, and fun descriptions.*

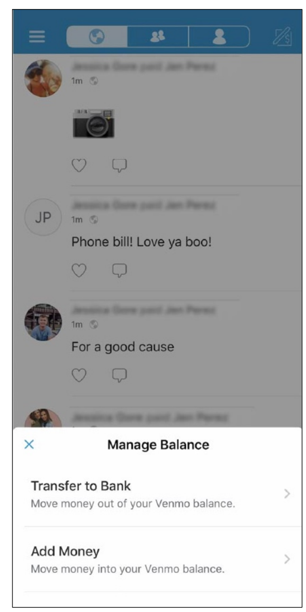

***Figure 4 –** Venmo has a stored balance function where users can keep money in Venmo to transfer to and from friends, or they can transfer it to their bank account for storage. It resembles a traditional checking account.*

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