Memory, Load, and Emotional Subsystems

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HF 700: Foundations in Human Factors

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Dec 20, 2021

Author Note: This expert review was a class deliverable and discusses the human working memory and the role of cognitive load and emotional subsystems like anxiety and motivation on human performance. I have reviewed a design case on the basis of the literature review, backed by scholarly articles.

Introduction

In order to perform tasks and interact appropriately with the external environment, the natural information processing systems of humans need to consciously obtain and process biologically secondary knowledge- that which has not been naturally acquired as we evolved (Coolidge & Wynn, 2005) (D. Geary, 2007; D. C. Geary, 2008). The evolution of human cognition allows us to integrate this novel, perceived information with prior knowledge, resist interference, enhance language, which impacts individual performance in areas like reasoning, planning, learning, decision-making, and general intelligence (Coolidge & Wynn, 2005) (Sweller, 1988). These processes take place in the working memory (WM), which makes the understanding of its nature and limitations crucial. The purpose of this paper is to discuss the limited capacity, time-constrained, and highly volatile nature of the working memory, how emotional subsystems impact the cognitive load it is under, and how that load is managed to aid performance. I will be evaluating the design case of cancelling a Dropbox subscription using evidence from the literature review.

Models of Working Memory

Earlier concepts of single-store primary and secondary memory (James, 1890) and models of sequential boxes with an attention filter keeping the sensory memory separate from short and long term memory (Broadbent, 1958), was countered in *Plans and the Structure of Behaviour* (Miller et al., 1960), where the term 'working memory' was coined and referred to as a multi-faceted system of temporary memory. Atkinson and Shiffrin's multi-store model also proposed three distinct types of memory – sensory, short-term, and long-term store (Atkinson & Shiffrin, 1968), but Craik and Lockhart's studies on levels of processing found inconsistencies in it (Craik & Lockhart, 1972). It was also considered overtly simple (A. D. Baddeley & Hitch, 1974).

Baddeley's Multicomponent Memory Model

The discussion of working memory includes not only the act of retaining a small amount of information, but also the executive control skills that are used to manage and cognitively process that information in working memory (Cowan, 2014). In 1974, Baddeley and Hitch formulated the multicomponent working memory model comprising of the central executive (CE), visuospatial sketchpad (VSS), and the phonological loop (PL) (A. D. Baddeley & Hitch, 1974), replacing the concept of the short term memory (STM) as an "acoustic, temporary, limited capacity verbal store" (Coolidge & Wynn, 2005). This model, revised in 1986, elaborated on the role of an attentional control system, i.e, the central executive (CE), adopting Norman & Shallice's model of attentional control (Norman & Shallice, 1986), a two-part system that controls automatic habits and a supervisory attentional system (SAS) that can override habitual responses (A. D. Baddeley, 1986). The purpose of CE is to direct attention towards relevant information (cognitive inhibition), divide attention between two concurrent tasks, and switch attention from one task to another (Logan, 2004). It also allocates data to the other two components (A. D. Baddeley & Hitch, 1974):

(a) VSS: the "inner eye" which integrates visual 'what' information (like, objects) and spatial 'where' information (like, location in space) elements, and maintains this by rehearsal. It helps us navigate. It comprises of the 'visual cache', which stores information about form and color and the 'inner scribe', which deals with spatial and movement information (Logie, 1986).

(b) PL: the "inner ear and voice", comprising of a phonological store of sounds and an articulatory loop to vocally/sub-vocally maintain and rehearse information. Its primary purpose is to evolve for learning and understanding language, and can be used to remember phone numbers (Coolidge & Wynn, 2005) (A. D. Baddeley & Hitch, 1974).

This model, however, could not explain the capability of processing information in chunks (Miller, 1956). The Embedded Process Theory came close with an explanation of ‘activated elements’ within the LTM (Cowan, 1999), used by experts (J. R. Anderson, 1983, p. 19), but could not explain varied processing of different modalities. A fourth component, the episodic buffer, was eventually incorporated into the multi-component model, which integrates visual, spatial, and verbal information in a chronological order with LTM (A. Baddeley, 2000). This way semantically associated elements (A. D. Baddeley et al., 2009) can be compared and contrasted simultaneously, which makes way for metacognitive problem-solving and planning capabilities (Coolidge & Wynn, 2005). The distinction between the four components of the multi-component model can be explained primarily by its nature and limitations of the WM.

Limitations of Working Memory

Certain limiting characteristics of the WM serve to protect the LTM from being overwhelmed by a large number of randomly generated, possible alternative organizational patterns of information processed by the WM (Sweller et al., 2011).

Limited Capacity

George Miller’s reference to a storage limit of “magical number seven, plus or minus two” in his theoretical review about increasing the span of “immediate memory” by intelligent grouping or “chunking” (Miller, 1956), alludes to the limited capacity of the WM. Luck and Vogel’s studies indicated that the visual working memory retains information about roughly four unidimensional stimuli at once by chunking their features meaningfully using pre-attentive resources (Luck & Vogel, 1997) (Treisman, 1996). Cowan’s more recent studies indicate that the number is more likely three to five, but this can vary individually (Cowan, 2010). Younger children have a smaller WM capacity that increases with age (Cowan, 2010), while older adults (60+) appear to be prone to WM decline (Zinke et al., 2014). Brain injury can lead to diminished WM capacity (A. Baddeley, 2012). Since individuals have limited attentional resources, the CE serves as a cognitive bottleneck by selecting only the most salient, goal-oriented information for processing in the other components (Broadbent, 1958).

Cognitive Load: Sweller (Sweller, 1988; Sweller et al., 2011) proposed the Cognitive Load Theory in which the attention demands or mental workload of a learner can be divided into three distinct elements: (a) *intrinsic load* which is the inherent complexity of the task to be learned, (b) *germane load* is the demand of resources required to learn the task, when the demands exceed the resource supply, there is cognitive overload, which leads to individuals adapting to satisfactory heuristics or shed tasks (Raby & Wickens, 1990), and (c) *extraneous load* generated by the manner in which information is delivered to the learner that inhibits performance and learning and often leads to learners making errors or users abandoning the task. (Engle, 2002).

Anxiety-ridden individuals may be occupied with concurrent thoughts of what might go wrong, which adversely affects the CE’s cognitive inhibition and switching capabilities, leaving less storage and processing space in an already limited WM (Eysenck et al., 2007). However, anxiety can lead to superior error detection and prediction skills in a domain of expertise, which leads to better performance (Darke, 1988; Williams & Elliott, 1999). Similarly, an individual in a motivated state of mind is more receptive towards novel information, which increases the processing efficiency of working memory (Eysenck et al., 2007) (Heckhausen & Gollwitzer, 1987). Experts are able to rapidly encode and bind frequently encountered, familiar chunks, thereby creating larger templates which are easily transferrable to LTM (unitization). On the contrary, novices rely on smaller chunks in the limited capacity WM and are more susceptible to interference (Gobet & Clarkson, 2004; Ye & Salvendy, 1994).

Time-Constrained

The Brown-Peterson procedure allude to the time constrained nature of WM, as well as the effect of rehearsal and interference on it (Brown, 1958; Peterson & Peterson, 1959). The contents of the PL decay within 2 seconds unless rehearsed verbally (A. D. Baddeley & Hitch, 1974) since items in WM decays in 2 seconds without rehearsal, and in approximately 18 seconds with rehearsal (Peterson & Peterson, 1959). Further research reveals that phonologically similar words are difficult to recall since the discrimination factor between the similar items is poor- the acoustic similarity effect (A. D. Baddeley, 1968). This effect is closely related to *proactive* and *retroactive* interference where similarity leads to confusion and disruption/distortion in learning, leading to forgetting. Proactive interference occurs when prior learning disrupts information recall (Keppel & Underwood, 1962), whereas retroactive interference occurs when you forget prior learning due to the learning of a new task (McGeoch, 1932). The word length effect states that recall is also better for shorter words since longer words take longer to verbally rehearse, thus allowing more time for decay in the phonological store (A. D. Baddeley et al., 1975). Similarly, recall accuracy varies with the serial position of an item on a list. The items at the end of a list are usually recalled first (recency effect) from the WM, whereas the first few items are more likely to be recalled than the middle items (primacy effect) from LTM (Deese & Kaufman, 1957; Murdock, 1962).

Studies have shown that cognitive performance anxiety induces fear and threat-interference that delays the WM (Angelidis et al., 2019). On the contrary, the competitive nature of humans decree that rewards, incentivization, monetary motivation all serve to increase WM efficiency (Murty & Dickerson, 2016). Elements which serve human's self-determination of autonomy, competence, and relatedness, aid WM performance (Maslow, 1943; Ryan & Deci, 2000).

Highly Volatile

Maintaining information in the WM requires effort- any interference/interruption is likely to cause loss of information and forgetting (M. C. Anderson & Neely, 1996), which shows how volatile it is. Two kinds of errors occur as a result of this: intrusion and transposition. Intrusion error occurs when an item is recalled that was not present in the list itself, and transposition error occurs when an item from a list is recalled correctly but in the wrong order (Henson, 1998; McCormack et al., 2000). The effects of volatility and thereby, errors, may be reduced and processing efficiency increased, by involving WM components in rehearsal processes like selective spatial attention for spatial WM (Awh et al., 1998), and aid the executive functioning of the CE to resist interference and enhance cognitive inhibition (M. Anderson, 2003; Banich, 2009).

Automated processes that demand lesser attention and only require effortless, rapid activation of underlying prior knowledge should be introduced (Ashcraft et al., 1992), while keeping in mind the declining control over inhibition due to aging, reading disabilities, etc (Chiappe et al., 2000). Stress, an emotional state of heightened arousal due to environmental factors and psychological factors like anxiety, can increase performance if the level is below an optimal threshold. Higher levels may, however, decrease performance as they begin producing attentional difficulties and higher cognitive interferences (Coy et al., 2011).

Case Study

Dropbox is a cloud-based file storage service that is often used for collaborative, real-time work. Its features include synchronization across devices, sharing large files, and auto-saving progress without the fear of disk memory crashes and losing work. It offers a range of plans for personal and business users priced accordingly, some of them also have trial versions that people can try for 30 days and then be billed monthly/yearly if the subscription is not cancelled. For this design review, we will discuss the process of a Dropbox Professional Trial user opting to unsubscribe from their free trial.

Dropbox does not alert free trial users that their free trial is coming to an end, an automated process that is likely to have reduced the extraneous load of our user who has to manually remember to cancel the trial on time, or be charged. Adding this alert would create the right support system for a user, reduce the load on the limited capacity of WM, and also build trust in the user's mind for Dropbox.

Fig 1: Dropbox Professional Home page

When creating a Dropbox account, it is advertised that the user can cancel or downgrade anytime, however there is no information scent/navigational cue in **Fig 1** for our user to know right away how they can perform the action. Exercising their acquired schema and WM, the user employs heuristics to reach the goal of unsubscribing before being charged and clicks the button on the top right, which mentions the Dropbox Professional trial.

Fig 2: Cancel trial button

The next page (see **Fig 2**) contains details of the plan and usage and a 'Cancel Trial' button with no contrast or highlight. So far, however, it seems straightforward and undemanding, and the user clicks it hoping to end the trial right away.

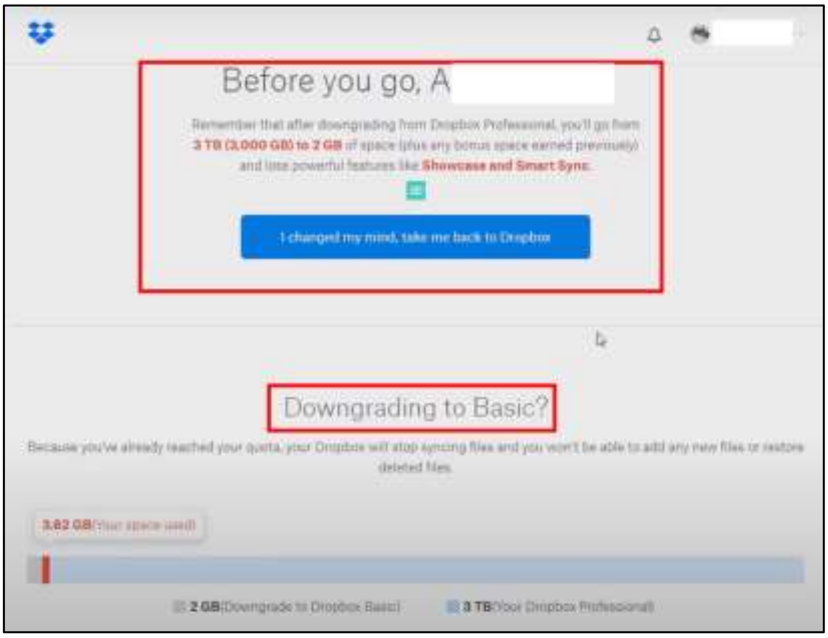

Fig 3: Downgrading to Basic

However, the next page (see **Fig 3**) starts with conversational content that attracts attention visually by calling out the user's name and activating their VSS. Using a high luminance red colour, which in some cultures denote danger or warning it highlights the negative effects of going ahead with the unsubscription task, nudging the user towards the CTA highlighted in blue: "I changed my mind, take me back to Dropbox". This is followed by more phrases with negative connotation like "Downgrading to Basic?" which triggers FOMO and anxiety in the user, adding load to the volatile and limited capacity of the WM.

A highly anxious user might forget their goal and abandon the task, an expert however would recognize this as a dark pattern and start scrolling to find the button that aligns to their goal. Further scrolling reveals the boldfacing, underlined in **Fig 4**, which also increases anxiety with the warning that the user might 'lose' if they go ahead. It is recommended that the "I still want to downgrade" button be highlighted to increase discrimination and reduce similarity with the other options that are not aligned to the goal. Options 1, 2, and 3 (highlighted in the screenshot) are distractions and cause interference, increasing the load on the working memory.

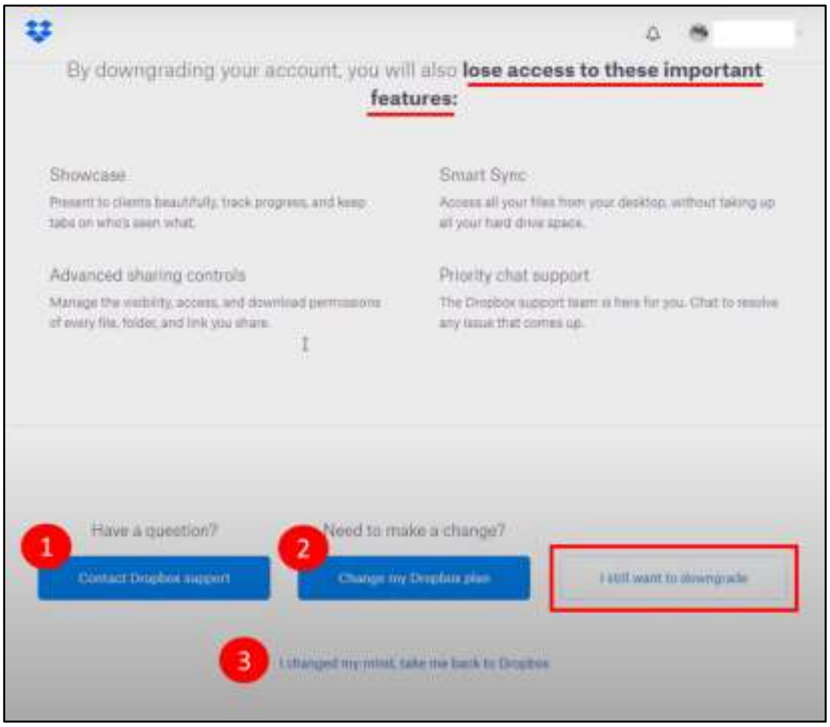

Fig 4: Losing access

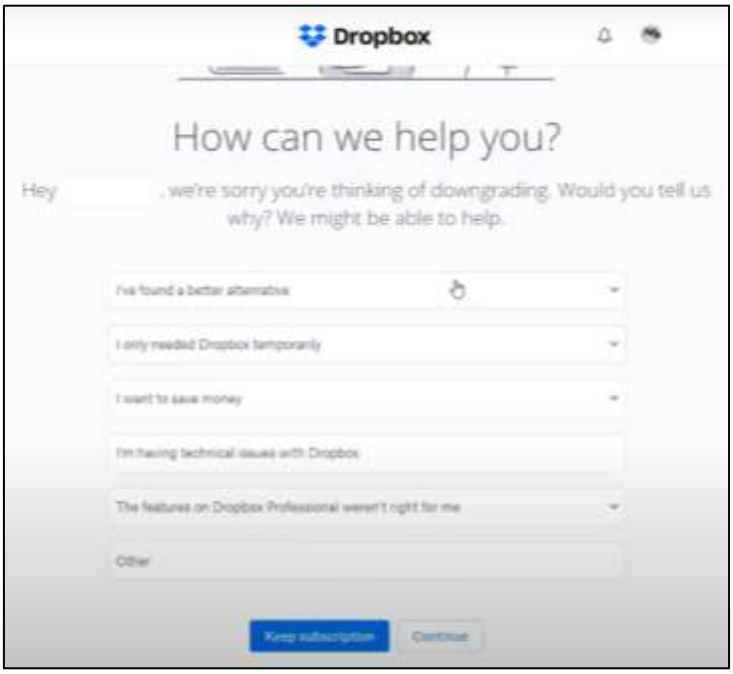

Fig 5: How can we help you, user?

Clicking the "I still want to downgrade button" in **Fig 4** takes us to yet another page (**Fig 5**), where the user is again called out by name, and offered help to create a sense of belonging. Options are provided which require the user to pinpoint the reasons for unsubscribing, an expert is likely to recognize the drop-down arrows as solutions and further steps that would distract/demotivate from reaching the main goal. An anxious, aging, confused user is persuaded to click the contrast sensitive "Keep Subscription" button as it offers the least load to a time-constrained, nearing fatigue WM.

It is recommended that Dropbox decrease the number of steps as it is demanding and requires more deliberate effort from the user, increasing cognitive load and affecting their performance.

Clicking "Other" and "Continue" takes the user to yet another page (see **Fig 6**) which requires the user to metacognitively think and answer why they are 'downgrading', which drains on the limited WM capacity. The user is further reminded of the negative information using "pop-out" techniques of red highlights, boldfacing, wrong button highlights to deter them from the task. The user can then click the "I still want to downgrade" button to complete the task.

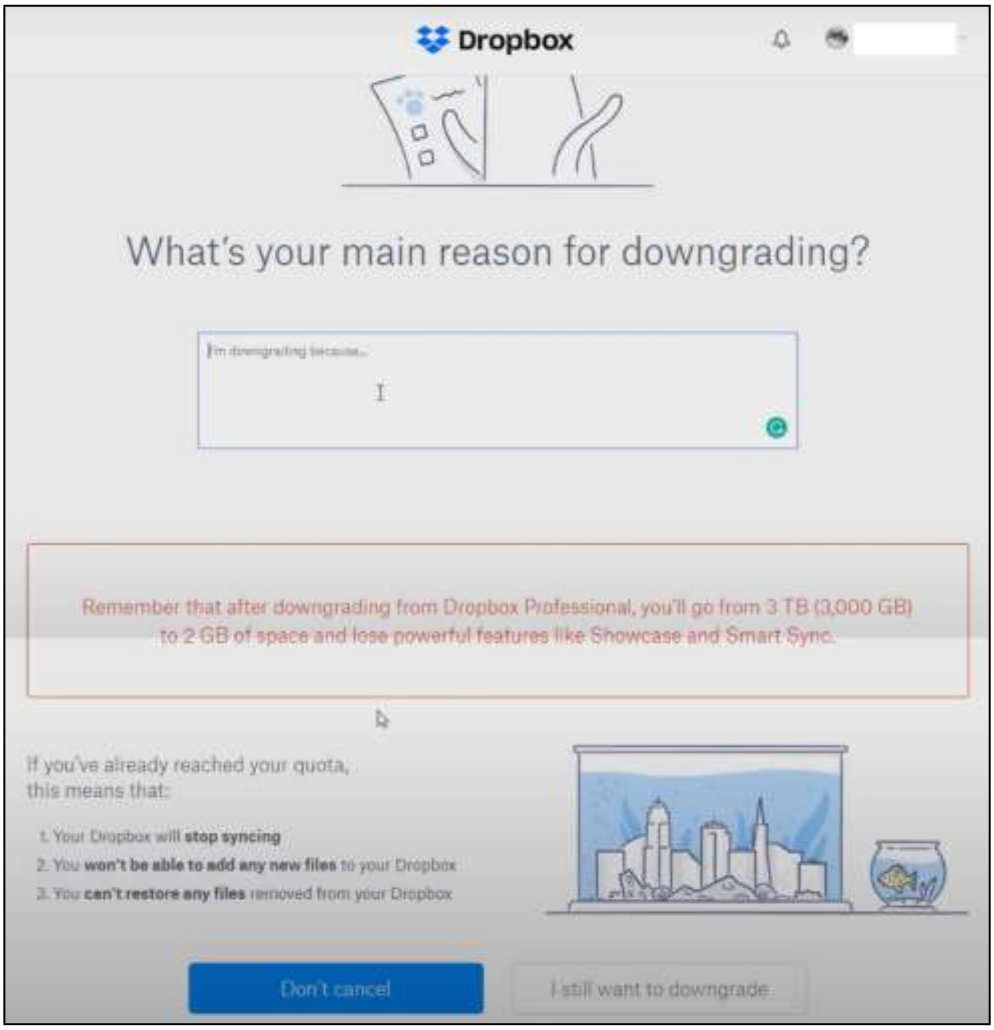

Fig 6: I still want to downgrade

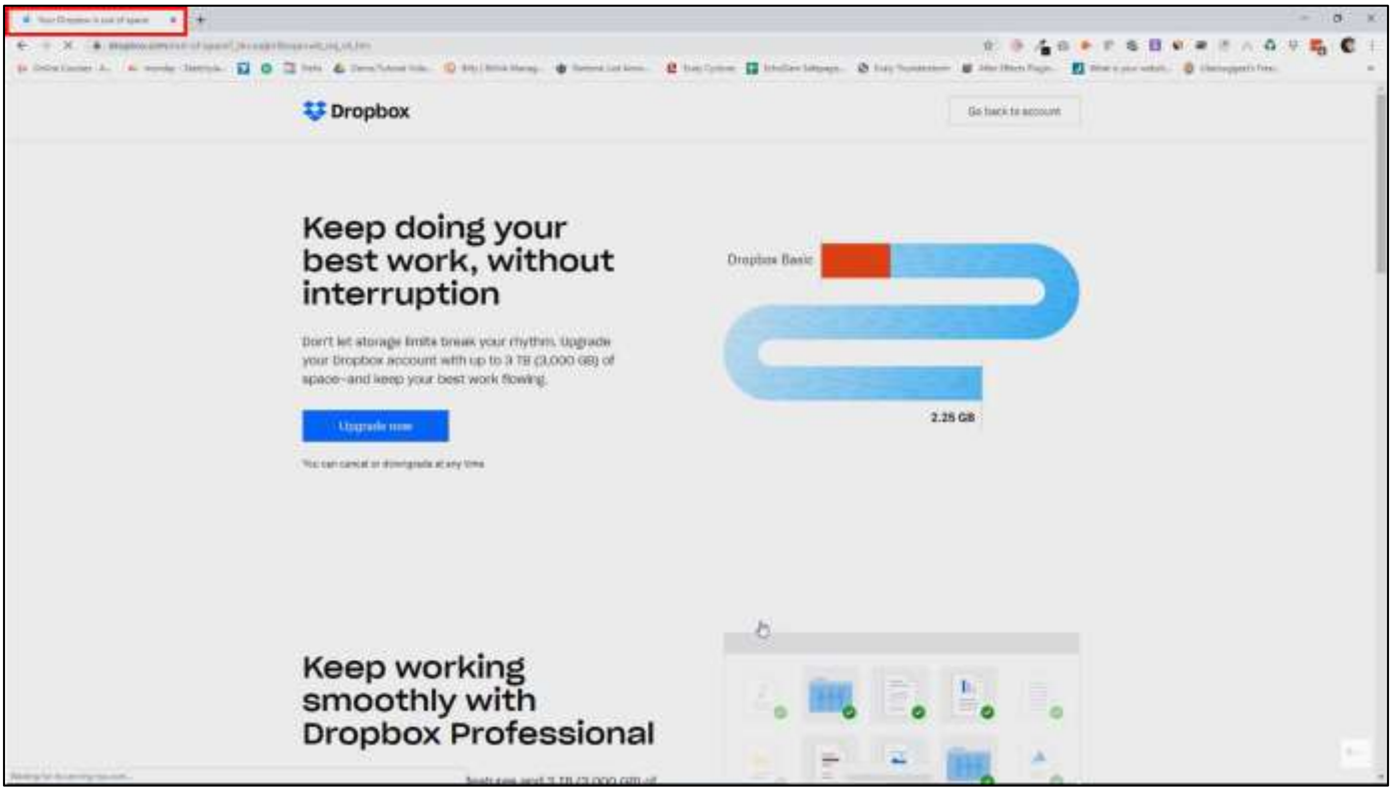

Fig 7: Your Dropbox is out of space

Note that the next page (see **Fig 7**) is called “Your Dropbox is out of space” which triggers anxiety. It is recommended that the following screen show the user that they have successfully unsubscribed, to avoid confusion. In conclusion, this process design is not tuned to the limitations of the WM, is likely to influence users to abandon task. Motivated users and experts might be spurred to go through with it and leave negative reviews, having lost trust.

Conclusion

It is important to be attuned to the nature of the limitations of the WM, and be aware of mental health on and off screen. As designers, it should be our goal to fight against dark patterns and persuasive technology and create designs which reduce cognitive load, and are not only responsive, but also responsible.

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