RESEARCH ARTICLE

Constructing a Choice-Boundary/Growth Mindset Model Through EDA and EEG

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ABSTRACT: Decision-making is becoming increasingly essential to a person's success in life. There is a generational shift from passion to practicality. For example, while Boomers and Millennials focus on finding a job that interests them and cultivates their passion, iGen (the current generation) has their eyes on the money earned for the job.

This paper studied a student's different reactions towards learning and the completion of tasks in an educational environment and analyzed the relationships between energy consumption and the type of choice a student makes using Electrodermal activity (EDA) and Electroencephalography (EEG). The results yielded the conclusion that based on the amount of energy a student can provide for the task, their corresponding choice can be determined and the boundary in which that student works best can be uncovered.

To represent this relationship, a choice-boundary model is proposed where energy consumption is expressed as a Lyapunov function of choices. The model expresses possible directions a participant might take when introduced to a task and outlined possible pathways the participant might take in the process of completing the task. What this model and relationship imply is that in an educational environment, there is a happy medium between passion and practicality, in which a growth mindset can be cultivated, and where choices and their boundaries are well balanced while also allowing learning development.

KEYWORDS: Growth Mindset; Neuroplasticity; Choice; Boundary; Lyapunov function; Electrodermal activity (EDA); Electroencephalography (EEG).

Introduction

Decision-making is becoming increasingly essential to a person's success in life. In her book iGen, Jean Twenge distinguishes specific differences between teenagers during the Boomer, Millennial, and iGen generations. One of the main differences occurs in the way youths view life and its purpose. In an iGen'ers typical education, many students think of school more practically in terms of economic and social benefit. This practical view reveals that students today are making choices and setting boundaries in a drastically different manner when compared to their older counterparts. One example of this change is iGen'ers opinion on jobs. While Boomers and Millennials focus on finding a job that interests them and cultivates their passion, iGen'ers have their eyes on the money earned for the job.[1]

Schools have always advocated for an educational environment that cultivates growth mindset. A "growth mindset" thrives on challenge and sees failure not as evidence of unintelligence but as a heartening springboard for growth and to a challenge student's existing abilities. On the other hand, a "fixed mindset" assumes that character, intelligence, and creative ability are static givens which cannot change in any meaningful way; striving for success and avoiding failure at all costs becomes a way of maintaining the sense of being smart or skilled.[2] Growth mindset is supported by neuroplastic tendencies of the human brain. The human brain makes a variety of networks as a child continues through their lives from learning of new tasks and mastering skills.[3] The "softwiring" and "hardwaring" of the human brain are constantly changing. While learning of a new skill "burns" new knowledge into the brain's neural network, (softwiring) mastery of a skill reuses and consolidates the brain's existing networks.[4] (hardwiring)

Passion or practicality and growth mindset or fixed mindset are among many decisions a student has to make. In Stephen Covey's 8th Habit Book, he states:

"Between stimulus and response there is a space. In that space lies our freedom and power to choose our response. In those choices lie our growth and our happiness."

Each student has their own preferences on the best way to learn, so growth mindset does not have a defined structure. Based on the amount of energy a student can provide for a task, their corresponding choice can be determined and the boundary in which that student works best can be uncovered. By implementing the variables of choice and boundary, students' personal "growth mindset" zone can be derived from a structured model.[5]

The paper is outlined as follows. In the first part of the paper, neuroplasticity and growth mindset are measured by using Electrodermal activity (EDA) and Electroencephalography (EEG). EDA responses are tiny electrical changes on the skin which may indicate the body's response to stress. This data was collected by applying a low, undetectable, and constant voltage to the skin and then measuring how the skin conductance varies. This can be done with EDA devices that measure the electrical signal recorded by electrodes applied to the skin. EEG info: The Muse EEG headband contains seven electrodes, two on the forehead (prefrontal cortex), one behind each ear (temporal lobes), and three more electrodes as references. The brain waves recorded with this device are

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signal moving between 3 mental states of calm, neutral and active. [6]

While EDA is a measurement of growth in the body's autonomic nervous system, EEG is a measurement of growth in the body's central nervous system. In the second part of the paper, a choice-boundary model constructed, where energy consumption is expressed as a Lyapunov function of choices. The model articulates possible directions a participant might take when introduced to a task and outlines possible pathways that participant might take in the process of completing the task. What this model and relationship imply is that in an educational environment, there is a happy medium between passion and practicality in which a growth mindset can be cultivated, and where choices and their boundaries are well balanced while also allowing learning development.

Methods

EDA as a measurement of neuroplasticity/growth via Choice Substitution:

For the EDA experiment, the objective was to observe sensory substitution and the "growth" in the body's ability to adapt to increasing task difficulty. The experiment consisted of a simple call-to-action activity (Bop-It!) and tested a participant's ability to use senses other than hearing to complete the same mastery score (i.e., performing 100 actions with increasing difficulty without mistakes). Earmuffs were used to block out auditory sensing, while the Buzz Band was placed on the participants lips to "feel" the sounds, and a sound wave app was used for the participant to "see" the sound. With all the substitutions combined, each test recorded how long the participant was able to correctly perform the actions inputted by the different devices. An EDA fingertip sensor was used to record the micro voltage (potential energy) that was experienced by the stimuli. In summary, it took thirteen days: 20 minutes (10 minutes choice original, 10 minutes choice substitute) in each experiment to develop matching skills between the choice original and the choice substitute (see Table 1).

Table 1: EDA Measurements Between Original and Substituted Senses.

No	Choice Original (also indicator of game difficulty)	Choice Substitute
1	0.2779	0.3141
2	0.9002	0.8023
3	0.6666	0.6263
4	1.2811	1.3427
5	1.7437	0.777
6	2.0933	1.4067
7	1.5677	1.6456
8	1.5302	1.3096
9	1.9449	1.1925
10	1.4457	0.6973
11	2.0321	1.7335
12	1.652	1.357
13	3.068	2.8607

"EGG info": EEG responses are recorded brain waves on the surface of the scalp which may indicate the brains response to stimulation and cognitive energy consumed. This data was collected through the muse EEG headband.

EEG as a Measurement of Neuroplasticity/Growth via Choice of Exploration vs Exploitation :

In this experiment, three participants were tested for an exploration task and an exploitation task. In the exploitation task, the participants would play a video car driving video game in a fixed environment with fixed steering controls. In the exploration task, the participants would read a classical novel (i.e., Lord of the Rings). In the same day, both tasks were tested in intervals of 10, 15, and 30 minutes, with 5-minute rests in between. For six days, this process was repeated, to gather all the data (see Table 2).

Table 2: EEG Measurements Between Tasl Duration and Energy Amount

Index	min	read-rest	game-rest	(read-rest)-(game-rest)
1	10	3.575222	1.1382728	2.43694901
2	10	5.40662	3.841237	1.565383087
3	10	2.703986	2.9260308	-0.22204534
4	10	2.299625	0.6717958	1.627829454
5	10	4.33242	0.8908769	3.441542962
6	10	1.482907	1.5138055	-0.03089807
7	15	3.950033	2.076292	1.873740705
8	15	4.086221	3.4164465	0.66977425
9	15	1.809697	-1.2625531	3.07225026
10	15	2.939217	0.2917803	2.647436178
11	15	0.512136	-0.1227801	0.63491589
12	15	1.997477	0.6678265	1.32965047
13	30	3.891807	1.366901	2.52490638
14	30	4.059761	2.4450469	1.61471414
15	30	1.359963	2.7251717	-1.36520892
16	30	3.56596	3.3502243	0.215735363
17	30	1.116727	0.7195272	0.397199536
18	30	0.667903	1.1520632	-0.48416022

Results and Discussion

EDA as a Measurement of Neuroplasticity/Growth via Choice Substitution:

The choice substitution by interchanging inputs from the senses in the human body revealed a relationship between time and the magnitude of energy required to accomplish a task. Specifically, auditory inputs were substituted by visual and epidermal inputs (see Figure 1). The main objective, therefore, was to observe the familiarization and mastery of performing a task. As the experimentation continued, performance on both the original and substituted senses reached an approximately similar endpoint. When shown side-by-side, the progression of "mastery" in both tests displayed relatively identical movements in energy consumption (see Figure 2).

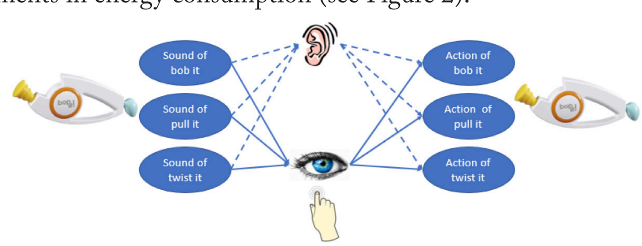

Figure 1: Diagram of EDA Experimentation. Senses with inputs of sound were substituted by sight and touch. The participant felt and viewed sound waves instead of listening to them. The changed inputs yielded outputs that highlighted the body's ability to adapt to difficult inputs and strengthen the new inputs to more efficient and accurate performance.

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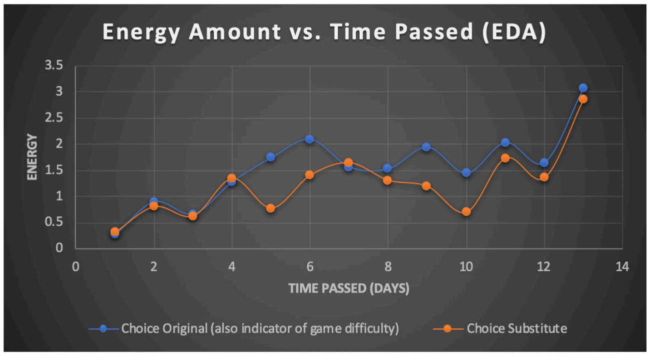

Figure 2: Relationship between Task Difficulty and Passage of Time in correspondence to energy usage. Both tests show an overall increase in energy consumption, and both tests converge to a relatively similar endpoint.

The underlying factor to the eventual conformity of both tests was choice. A participant could either perceive a task competitively or casually. The choice to perform well caused the intentional increase in energy usage in order to reach the required completion of the task (in this case, performing 100 actions with increasing difficulty without mistakes).

When exposed to a new task or assignment, the human body uses the multiple sources of inputs from the senses to gather background information, to observe, and to establish a foundation. For both tasks, the improvement follows a similar increase of energy consumption. Compared to the sensory inputs from the most familiar and efficient source(s) (i.e., hearing), the brain takes more time to adapt to slower and less efficient substituted sensory inputs (i.e., sight and touch). After familiarizing the procedures and mechanics of the alternative sources, the brain's performance on the task slowly approaches the energy level of the tests with no sense limitations.

EEG as a Measurement of Neuroplasticity/Growth via Choice of Exploration vs Exploitation:

In tandem with the EDA measurements, the measurements of EEG were also used to observe the changes in energy consumption for tasks over the passage of time. The objective of this experiment was to investigate the relationship between task duration and energy consumed. A key factor to highlight is the distinction between an exploration and exploitation task. An exploration task absorbs new information and converts it to familiar information over time, but an exploitation task takes familiar information and strengthens its performance over time (see Figure 3).

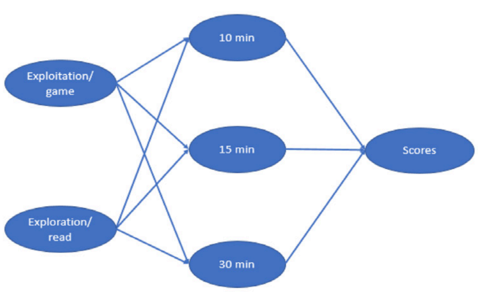

Figure 3: Diagram of EEG Experimentation. Exploitation task (game) and exploration task (read) are tested in 10 min, 15 min, and 30 min intervals with 5 min rests in between. The comparison yielded the conclusion that while each task starts at a different position, the amount of energy needed to complete both types of tasks eventually converges over time.

The difference between the two tasks is what a participant experiences at the beginning of the experiment. Since the exploitation task simply repeats a previously performed task, it will begin at a relatively low energy consumption and this consumption will stay in its low position. However, the exploration task constantly inputs new information; it will begin at a relatively high energy consumption. The nature of longer task duration displays an inverse correlation with energy consumption. The more familiar a participant is with the task; the less effort and exertion is needed to complete it. Although each task starts at a different position, the amount of energy needed to complete both types of tasks eventually converges (see Figures 4 and 5).

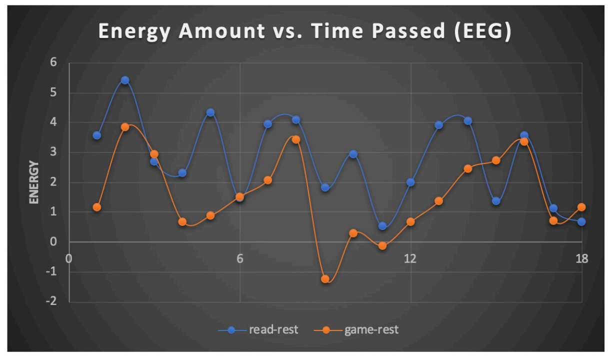

Figure 4: Relationship between Task Duration and Passage of Time in correspondence to Energy usage. Both tests have an overall decrease in energy consumption, and both tests converge to a relatively similar endpoint as well.

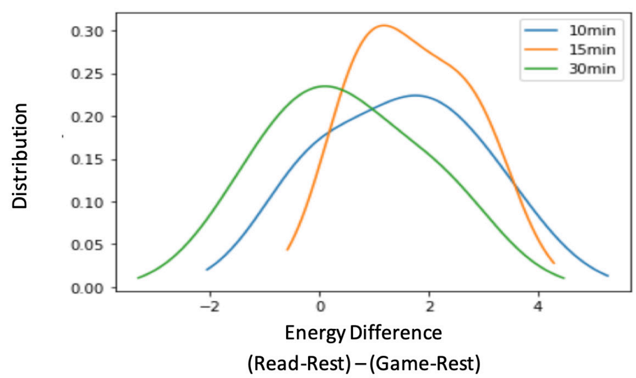

Figure 5: Distribution of Energy in Task Completion in correspondence to Task Duration. The graph shows that as task duration increases, the average energy usage decreases.

Choice and Boundary Model for Growth Mindset:

From the above experiments, it can be observed that for every choice made, a specific amount of energy is needed (i.e., time and effort). Yet, energy is limited by both its supply and its demand, which in turn set the boundaries for the choices that can be made. To represent the relationship in the above two experiments, a choice-boundary model is constructed, where energy consumption is expressed as a Lyapunov function of choices (see Figure 6). Specifically, the vertical axis is V, the energy consumed, the two horizontal axes are X1, task speed or the inverse of task duration, and X2 which is task difficulty. The Lyapunov function represents a model of a dynamic system. A stable dynamic system gradually loses energy (dissipation) and settles to the bottom of the bowl. An unstable dynamic system gradually increases energy and particles will keep rising to the top of the bowl. Unlike a simple dynamic stable system which eventually reaches a stopping point, humans are complex systems; the life of humans can be imagined to be tan unstable dynamic system. The gradual increase in energy can be represented as, occasional pushes which keep the pendulum in motion. These occasional pushes are directly connected to choices.[7]

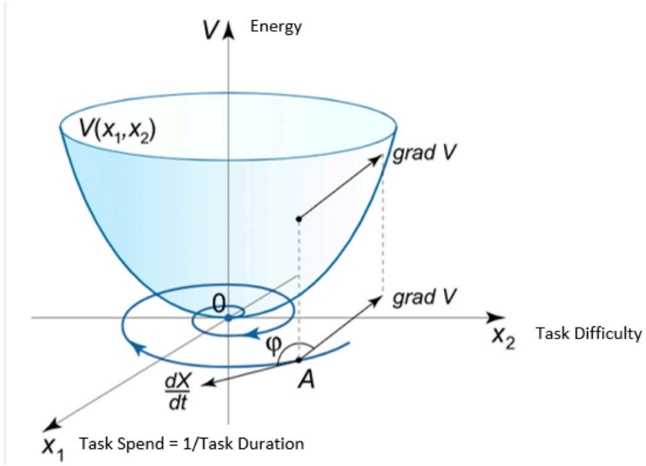

Figure 6: Diagram of Lyapunov Function, which shows that all stable systems eventually spiral down to a resting state.

The choice and boundary model expresses the direction of human behavior towards a growth mindset and mastery of tasks. One aspect of this model shows an upward and downward route. The upward route encourages the choice of increasing task difficulty which cultivates extended boundaries and additional opportunities. The downward route encourages the choice of task mastery via longer task duration with task completion more automatic and with less energy required.

This model acknowledges that there are specific characteristics in each choice that people could to be aware of. From the model, one who chooses to pursue one's passion (upward direction with law task duration and high task difficulty) is vulnerable to stress because the boundaries presented consume too much energy. Therefore, people may experience the feeling of lagging behind the required level of activity. A balance must be established between energy demanded and energy supplied in order to preserve a constant positive momentum in life. By keeping this momentum, one can prevent the issue of overworking.

On the other hand, with high task duration and low task difficulty one who chooses to focus on practicality (the downward direction) may be vulnerable to monotony because the boundaries presented consume little to no energy. Therefore, people may experience the feeling of disinterest or lack of exploration. In this case, the boundary limits a person's ability to discover new things among his or her small range of activity. A balance must be established between energy demanded and energy supplied to preserve a constant positive momentum, but also to prevent oneself from arriving at a dead end (i.e., reaching zero in the Lyapunov function).

This model can be applied in two different ways based off choices. The first way is to decide whether the task is constantly changing or if it is static. In relation to what was explained above, the tasks that change will most likely require a person to explore through trial-and-error and expose them to multiple high risk, high reward situations. Therefore, the best choice would be to adapt to the mindset of the upward direction. The increasing task difficulty, according to the model, demands more energy from the person, but allows him or her to find and pursue interests. If the task is already defined by a specific boundary, it will most likely require a person to perform more efficiently and expose them to routines. Therefore, the best choice would be to adapt to the mindset of the downward direction. The increasing task duration, according to the model, demands more stamina from the person, but allows him or her to become a master of specific skills.

The second application is choice blending. It is true that a person might not follow the model's recommendations to the extreme. There must be a happy medium in which both passion and practicality are implemented into daily life. A second representation of the model shows specific ranges where both choices can be blended. The ranges do not necessarily define a person's boundaries, but it does distinguish the places where the two dimensions of choice can be blended (see Figure 7).

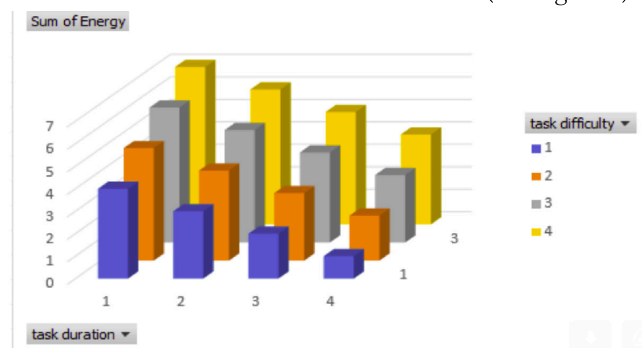

Figure 7: Choice blending of Choice-Boundary Model shows the different amounts of energy in terms of task duration and difficulty. The bar graphs also show that one energy requirement includes, but is not limited to four different ways of dispersing task duration and difficulty.

According to the bar graph, task difficulty changes by color (blue= low, orange= low medium, gray= high medium, yellow= high) and task duration changes from left to right in increasing order. With the two factors combined together, a total energy requirement can be determined. A task that is easy will require the same amount of energy in a short amount of time as is a task that is hard that takes a longer duration. For example, completing a task that requires an energy level of 4 presents four possible combinations of duration and difficulty. A student can decide which combination is best for him/her. Specifically, when presented with a task that demands high energy usage, a student may choose to increase the time of completion to reduce physical and mental stress while improving skill mastery. The opposite operates similarly. When presented with a task that demands low energy usage, a participant may choose to shorten the time of completion to reduce boredom while improving time utilization. Each student has his/her own abilities and perception of challenge; this model can be used to plan the strategy to implement a growth mindset.

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Conclusion

The ideal balance in which a student can develop a flourishing growth mindset is where energy is used and spent productively and wisely on the task. Given the limit of a student's effort, both the difficulty and duration of a task can be altered to provide enough interest for the student to be motivated intrinsically in the process of completing the task, but also enough flexibility to allow for the student to rest while continuing to encourage exploration on his/her own time.

The EDA data expressed the relationship in which the harder the task becomes, the higher the energy demand was for the participant to adapt to the challenges. The EEG data expressed the relationship in which the longer the task becomes, the lower the energy demand is. Thus, the participant can complete the task efficiently. Both cases showed the existence of growth in terms of learning of new skills and mastering of existing skills.

The model proposed can represent some of the many dispositions a participant may exhibit under a growth mindset. A task can be hard, but the participant can complete it in small steps. Similarly, a task can be long, but the participant can break the time into segments, each having its own specified difficulty. In both cases, the student is using the divide-and-conquer strategy, accumulating energy for increasing energy demand. On the other hand, a task can be easy, but the participant can become master of the skill and to improve energy utilization or complete it in a shorter amount of time to improve time utilization. A task can be short, but a participant can prolong task duration in order to explore more aspects of the task, or to extend its concepts to other disciplines. In this case, a student is using the short task to share duration and difficulty with other tasks.

In summary, the experiments and the model present possible directions a participant might take when introduced to a task and outline possible pathways the participant might take in the process of completing a task. What this model and relationship imply is that in an educational environment, there is a happy medium between passion and practicality, in which a growth mindset can be cultivated, where choices and their boundaries are well balanced while also allowing learning development.

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