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Ureka Potential

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Abstract. This fictional prototype appraises recent advances in the fields of intelligent glasses and brain computer interface technology to address possible impact on a more immersive style of teaching and learning. The former advance can be used to measure eye gaze and hence to assess whether a student is at least looking in the correct place and possibly attending to lecturer or computer screen; the latter can measure and quantify changes in brain activity. Could changes in brain activity be used to signal cognition and acquisition of knowledge or understanding? This is a much more ambitious goal and the prototype extends current achievements in electrophysiology to unearth an 'understanding' component, termed here the 'Eureka Potential'. Two exhibitions which ran concurrently over the summer in London at the Victoria and Albert museum, "David Bowie Is" and "The Memory Palace" provide the inspiration for the piece. The motivation for this work is that assistive technology could encourage our students to become more 'active' learners.

Keywords. Brain computer interface, intelligent glasses, teaching, learning, "David Bowie Is", "The Memory Palace".

1. Introduction

The backdrop to this work is the serendipitous colocation of two exhibitions at the V&A during June 2013. The first "David Bowie Is" was a retrospective testimony to musical and artistic genius. This is a subjective experience, in the eye of the beholder. The second, "The Memory Palace" warns of the danger to future digital society of loss of technology. In the Orwellian society that emerged, at an individual level a citizen's memory was controlled. Memory of course underpins all cognition, understanding and creative thinking, even genius.

The paper uses a water metaphor, which flows through the different sections, in search of a potential, until the author declares, "I have found (it)".

Of course the focus of the work is immersive education, and technology that supports it. Intelligent glasses can provide an objective measure of engagement. But how do we as teachers know that a student has understood a topic?

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2. Discussion

The paper addresses education and the problem of assessment. For example, in an examination, if a student replays a 'stock' answer to a question, have they really understood the topic? This is manifest to the author in the discipline of Computing and Mathematics. In this subject problems that have been previously seen can normally be solved by students, but performance falls off for questions which require 'problem solving' skills. In programming for example we try to teach core problem solving skills from the bottom up in year one of an undergraduate degree, but sometimes a weaker student simply searches the Internet for solutions to problems, often tweaking variables without really understanding the consequence, sometimes even by trial and error.

To engage the students many departments have used exciting interactive technologies such as Mindstorm's Lego robots, Robosapien and novel input mechanisms such as Nintendo Wii motion plus and Microsoft Connect. Indeed working in multimedia design or in game design is often the expectation of the student and motivation for the course in the first place. Novel use of technology can have beneficial engagement effects over the standard integrated development environment (IDE) for learning programming skills, particularly in a team environment. Yet most of our employers still seek students who can 'program', often for the financial sector, with commensurate rewards. This really means students who can problem solve.

However technology continues to improve and throw up unanticipated consequences for its application. This prototype addresses such technology for application in immersive education.

3. Fictional Story

3.1 Lecture Theatre May 2014

As I finished my final lecture of the semester to the normal hub-hub of relief for all concerned and looked up to my audience, now paying customers, a door at the back of the theatre opened purposefully, a burly customer entered the lecture theatre and descended towards me. His eyes were transfixed on mine, as he made his way down the stairs, seemingly oblivious to the tide of final year students leaving. I knew why he was here. He was a first year student from my computer networks class, indeed by all accounts a particularly good student[2].

3.2 Two faces of life: 22 June 2013

I had just left the "David Bowie Is" exhibition at the Victoria & Albert (V&A) Museum. Most V&A exhibits portrayed long deceased characters taken from a dour fourth form history, art or music lesson – Archimedes, Van Gough, Mozart and many more of our forebears touched by genius; Bowie was

[2] The scenario was inspired by colleagues at an evening meeting in Colchester, Sept 2013

an exception to this, as befitted his esoteric music career, the "Is" was crucially important, he is still alive[3]. The trivia and memorabilia were encased in glass and the vivid stage costumes on display conjured up Bowie's stage and screen personae, a series of iconic instantiations from the David Jones[4] template, each with a distinctive look, like a Japanese kabuki [1] character's mask. The popularity of the exhibition[5] cascaded the visitor along a current of people, old and young, flowing from entrance to exit, accompanied by a whirlpool of sound and vision, an immersive 'mash-up' of his 70's and 80's songs. Bowie's songs acted like a switch and instantly ignited my memories of the fourth form disco, shoulder length hair and blue jeans, riots on the streets of Belfast, and the imminent arrival of aliens from space; definitely no school lesson in this museum. The 'David Bowie Is' experience kindled my optimism.

"I'm not a prophet or a stone age man, just a mortal with potential of a superman" [2]

These lyrics resonated around and around in my head, swirling in a continuous loop. I had long since believed that Bowie was indeed a latter day prophet, and it goes without saying, a superman. He was a creative genius, often blazing a path where his peers, some mere mortals, others definitely from the Neanderthal side of the spectrum, meekly followed, often releasing pale imitations of the master's work, like fake Van Gough's paintings. Where did this creativity come from? The exhibition portrayed his upbringing in Brixton, an unremarkable youth, no Mozart child genius, somewhat overwhelmed by the intelligentsia and artisan 'in-crowds' of Soho's swinging 60's. Then it all changed as he grew to a twenty-something, like a switch. What if we all had this potential for creative thought, I pondered? It may just be a matter of flicking the switch.

My research had centered on 'potentials', electrical ones from the brain, so I tried to decipher the deeper meaning in the lyric. I was sure the 'prophet' has a message for me.

As I was about to leave the V&A to meet up with a group of similarly minded Bowie followers, I noticed a disturbing image in my peripheral vision. It was a display banner advertising a "Memory Palace" [3]. It provided a "dramatic vision of the future through an immersive exhibition experience". I assumed it was co-located by chance. The title intrigued me – I decided to go in to experience the author, Hari Kunzru's future vision [4]. The first poster in the exhibition confirmed my curiosity.

"Hari Kunzru's story is set in a future London, hundreds of years after the world's information infrastructure was wiped out by an immense magnetic storm. Technology and knowledge have been lost, and a dark age prevails. Nature has taken over the ruins of

[3] David Bowie's latest album "The Next Day" has been nominated for the 2013 Mercury Music Prize

[4] David Robert Jones was born in Brixton (8 January 1947), he is better known by his stage name David Bowie

[5] 'David Bowie Is' was the most popular V&A exhibition ever, with reserved tickets completely sold out, night-time slots and long morning queues for the remaining day tickets

> *the old city and power has been seized by a group who enforce a life of extreme simplicity on all citizens. Recording, writing, collecting and art are outlawed."* [3]

By contrast there was no tide of people in this room, a still silent V&A backwater, where the few visitors meandered from station to station. This Palace was not a happy place. The narrator of the story, a dissident in the Palace, was trying to hold onto his memory. It presented a dystopian view of the future, where society dictated that citizens were 'programmed' to conform, a subject coincidentally envisioned by Bowie in his 'Future Legend', a version of 'Metropolis' [5].

"If you could keep only one memory, what would it be?"

This was a tag line for the exhibition. My thoughts lingered on our recent Alzheimer's assistive technology research work, a depressing proposition indeed, if all our citizens suffered these symptoms of memory loss [6], destined to repeat some small set of meaningless phrases, before they too faded. Some dissidents in this future world did what they could to retain their free thoughts and save their memories; but the narrator of the Palace ended up in prison.

> "*..accused of being a member of a banned sect, who has revived the ancient 'art of memory'. The narrator uses his prison cell as his 'memory palace', the location for the things he has remembered: corrupted fragments and misunderstood details of things we may recognise from our time. He clings to his belief that without memory, civilisation is doomed."* [3]

The Palace provided an antidote to my Bowie induced 'high', no creativity, society in a downward spiral, a Tower of Babel [7] in the digital age, yet to come.

I pondered on the education process, and reflected that nowadays students were being similarly programmed, fed information which they would duly regurgitate to show they had 'understood', but I doubted it. New tasks would often initiate a quick surrender; problem solving and creativity were being stifled. Information was now disposable, to be consumed, filed away in the cloud, then seemingly forgotten. Were we in danger of taking a step closer to this future legend? Of course I blamed the 'system', which absolved me. This tempered my optimism, a little, until I left to meet my colleagues in a nearby pub and my memory dwindled, aided by a relay of 'Metropolis'[6] real ale.

But I was left with a question. How could teachers inspire students to be more creative, like Bowie's lyrics had inspired me? At least students could still write down to help them remember (or download, ….hmmm!) but how could

[6] Metropolis, "A superb golden session beer, with enormous balance and depth of flavour and a long floral, spicy finish."

we know that they understood the subject? How could they put the fragments together? I was in danger of becoming a Palace dissident.

3.3 A perfect storm: May 2014

My London trip was filed in my own Memory Palace (for later regurgitation, of course), I was back in my day job end of semester; sometimes a teacher, sometimes a researcher, a confused academic struggling with the paperwork in my paperless office. I filled in my Higher Education Statistics Agency transparency return form which detailed my effort: 50% time on teaching, 50% time on research, not too hard, although increasingly it seemed that much of my time was spent on filling in forms.

However, my research had gathered new impetus this year. As a post-doc researcher I had been involved in the investigation of brain electrical signals, the electroencephalogram known as the EEG. The EEG had been first recorded by Hans Berger [8] in the 1924, a scientist, prone to bouts of depression, but undeniably touched by creativity[7]. By using various sound and vision stimuli a class of diagnostic brain electrical signals known as event-related potentials could be generated for subsequent analysis. These potentials were powerful indices of the function of the brain; some could be used to objectively assess sensory function such as hearing and sight, others were diagnostic for degenerative neural conditions such as multiple sclerosis, epilepsy, even brain death. My own research focus had been into the cognitive potentials. Some excellent work had been done by to identify the various important cognitive 'waves': the P300[8], the N400, the mismatch negativity (MMN), the contingent negative variation (CNV); all useful to psycho-physiologists in the study of memory, attention, and even the understanding of language.

In the 'noughties', the fusion of Human Computer Interaction with recorded EEG spawned the area of brain computer interface (BCI); I duly got involved in this research stream, as befitted my teaching role in Computer Science. BCI was set to be the next 'big thing' for accessing computers by thought alone, but the research had stalled for some years, leaving those involved to devise ever more complex signal processing algorithms to show modest increases in classification accuracy for one or other classification model, using well-worn datasets.

But in Sept 2013 came a disruptive change, a new headset designed by Tan Le and funded by a Kickstarter crowd source project changed everything [9] – the 'Insight' would provide a paradigm shift. EEG caps were now designated as brainwear!

> *"A sleek, multi-channel, wireless headset that monitors your brain activity and translates EEG into meaningful data you can understand."*

[7] Berger eventually succumbed to suicide like many touched by genius

[8] The labelling implies a positive peak 300 msec after a stimulus to the subject; P300 is important in memory update

The headset was technically limited by neurophysiological laboratory standards; it had only 5 EEG channels; but multimodal add-ons included a 6 axis inertial sensor (gyroscope and accelerometer) and 3-axis magnetometer. As it cost only a couple of hundred dollars; it could be treated as a computer peripheral, a bit like a 'souped up' mouse. The headset could be applied in seconds. Indeed I had dreamed of such a device [10].

Better still my research group had found a way to solve the tricky problem of electrode reuse. With the advent of 'dry'[9] electrodes, it was possible to make disposable electrodes from plastic, of all things. The electrodes had to replicate the intricate shape to fit the headset. But of course this could now be done cheaply with a 3D printer, giving a potentially unlimited supply, for extensive reuse. The 3D printer provided a new way to make things that could be drawn on a computer cheaply.

These technology advances had come hot on the heels of 'intelligent glasses' [11] These glasses could be programmed to measure eye gaze, meaning that when a student looked at a computer screen, it was possible to track the areas that he/she was attending to.

For my research area, this was a perfect technological storm.

BCI could be enhanced by this technology. This was really exciting. By combining eye gaze and BCI our lab had already built a 'hybrid BCI' that outperformed our previous BCI systems, and in addition, the hybrid technology was robust, reliable and easier to use [12]. With the addition of the Insight headset it could be aesthetically pleasing, even cool. The eye gaze was measured unobtrusively by the glasses and linked with the BCI allowing menu selections on a computer interface to be made using BCI, eye gaze or both in collaboration.

3.4 Another Brick in the Wall

How can we be sure that the students attend to our lectures? How can we be sure that the student has understood a topic? These two questions were the holy grail of pedagogic research.

The first question had become easy to answer.

If student wore the intelligent glasses then it was straightforward to work out if the student attended to the lecturer (in the seminar) and the computer screen (in the lab). At the end of a class the lecturer could view summary data pinpointing any students that tended to stray 'too much'. Feedback to the student[10] could be instant, initially causing a fair degree of alarm – 'big brother' [13] had arrived in the classroom. I had used the system throughout the semester and I was surprised how quickly the students accepted it, but of course students of computing are early adopters of 'cool' technology. I felt that the technology was having a positive effect and this spurred me on.

[9] Previous electrodes required gel

[10] A student was now of course a paying customer demanding value for money

The second question was a little more complex.

For the last 20 years in cognitive research, neurophysiological researchers had been looking for the 'next' event related potential wave; something that demonstrated cognition. There were many such candidate waves distributed all over the scalp, but their patterns were illusive, not reproducible. We had got lost in the laboratories; too many electrodes, algorithms that indeed were too sophisticated, a feature set that had exploded. We were a victim of BIG data, drowning in the deluge. We had been looking for the 'needle in a hay stack'. There were just too many needles.

But over the last couple of weeks in the BCI we had been recording with our PhD students, a clever bunch. We devised a set of problem solving questions and monitored the brain activity, using our newly acquired Insight headset.

The years of toil were about to pay-off. Little did we know that the answer to our understanding process was there all the time, but occurring much later in time than researchers had been observing. It was very easy to miss. When a test subject solved a particular problem, an event was embedded with the raw EEG data, and an off-line algorithm mined the EEG channels for discernible features. The peaks and troughs in the EEG came and went. We needed a way to visualise the activity, so we hooked up the analysis software to large display screen and pondered, numbers were translated to colours, and we waited for patterns to emerge in space and time. This was 'CSI - Jordanstown'[11]. We could see some classic waves ebb and flow. We stopped the analysis after about 2 seconds and the EEG had returned to background levels.

Coincidentally we had just taken on a sixth form student, to give him some experience as part of a STEM[12] placement. On first impression the student, Archie, was the typical 'geek' programmer, good with computers – less so with people, really a young version of 'Brains' from Thunderbirds [14]. One afternoon we demonstrated the hybrid BCI system, to give him a project to present for his presentation day, a requirement of the placement. He was very enthusiastic and could program, but he didn't have our expertise and experience of course. He duly underwent the recording procedure and I left him to analyse his own data using a simple MATLAB routine. Later I returned to the lab to help him. It was a bit of a mess, not unexpected of course, 'rookie' mistakes. "The magnetometer and inertial data are completely different from the EEG, why did you subtract the vectors?", I queried using my authoritative, academic kabuki mask. "The evoked potentials finish after 2 seconds post-stimulus, I continued, there's no need to continue..." He wasn't attending to my comments, but excitedly showed me the pictures of his brain wave on the screen. Initially I wasn't attending to his comments. It would probably suffice for his project, I reassured myself. Then I noticed an interesting pattern in my peripheral vision.

Of course the EEG waveform, contaminated with magnetometer and inertial sensors data was all 'noise', pretty but completely corrupt, ebbing and

[11] Akin to Crime Scene Investigation_NewYork, http://www.cbs.com/shows/csi_ny/

[12] STEM: science technology, engineering and mathematics

flowing with random swirls for a couple of seconds. But then it happened; arriving like a giant tsunami wave that washed over the brain emerged a 'slow' wave, only observable subtly in the time waveforms as a small dc shift. We could only see it begin to emerge after about 1900msec and it lasted for at least a second; spatially it moved around the brain sites, detected first by one electrode, then another; as realisation of the 'answer' to a question in the subject's brain emerged at the frontal cortex, built up and then moved clockwise to the right temporal lobe, then occipital, then the left, and then the front again. It appeared that as an event occurred, as a question was answered, 'cognition' was being achieved and the answer filed to memory, then checked as part of intra-brain communication and a form or brain democracy. And then, a second identical pattern, like Usain Bolt[13] on a celebration lap as it became apparent to the source (i.e. the human mind) that they 'knew' that they knew it! But the shift was only there in the 'hybrid' system and best observed in a simpler system, like the Insight.

But why were we seeing it now? It was pure serendipity. The EEG by itself was too noisy. In labs there were too many channels. By subtracting the magnetic field and compensating for movement, using crude subtraction, the dc shift pattern could be sustained, after the EEG potentials had normally ebb away. I thought, "Brains, no Archie, he's a genius!"

A few weeks work with our PhD students followed. The pattern was reproducible in our lab. Well, with this potential we could now objectively test if a person really 'knew' an answer to a question. Think of its effect on teaching and learning; this could for the first time become a shared collaborative and measurable paradigm. This was a game changer; no longer would a student be able to claim that they understood a topic, a memory dump was no longer a substitute for 'active learning'.

3.5 Testing Times

Twenty first year students filed into a computer lab to take their final part of their year 1 Computer Networks assessment. At the instructor's desk I could check on an individual's progress or choose to view a 'dashboard' summary of attention as measured by each student's glasses. Each student donned the intelligent glasses. I told my students,

"Think about it, I know where you are looking". "For this final test I would like you all to wear a BCI headset", I said. "The test is only worth 5%, but I want to check your understanding of our subject, I said".

Puzzled looks from the class, but the glasses had been such a hit so no revolt. The test began. I checked my eye gaze metrics. The students were looking at the test, a few distractions but totally acceptable. Task 1 accomplished, they were engaged, but would they demonstrate cognition – acquisition of knowledge?

The test was designed to be pretty easy as first, to encourage the student, and then become a bit more tricky as time progressed. The data was streamed to the computer for analysis in the lab. Twenty questions to provide my

[13] Usain Bolt is the Olympic & World 100m & 200m champion and officially the 'fastest' man on earth

objective test of understanding, five straightforward recall, ten which required some logical deduction and five which required significant problem solving.

The off-line process was automated and quite fast, being visualized a few minutes after acquisition. The 20 student hybrid EEG patterns were displayed on a 5 x 4 grid. As the test questions kicked in, and following the data processing delay I could begin to visualise the brain waves of the students, and then the tell-tale circuits of EEG (and subsequent victory laps) began to emerge. As the test became more difficult, the performance fell off, just as I had anticipated. The marking was anonymous and automated; 1 mark for each question which elicited the double-lap cognition pattern, with marks returned directly to an-online student system.

3.6 Lecture Theatre May 2014

The first year student was clearly perplexed. “I paid the money and this is all I got in your test. I got good marks in my other modules, I just don’t UNDERSTAND”. “I know”, I said, “UREKA”.

This was my confirmation; the potential could be collected in the classroom. Using this potential the students could work at a topic until they understood it. We had a potential switch for understanding. I had the research algorithms, real world data and now user feedback. I could write a really important paper, even if I had to give way to my genius sixth form student. I started to write the first draft:

> *Title: Ureka Potential: An objective EEG measure that can measure cognition for use in and Immersive Education Environment*
>
> *Authors: Archie Medes, Paul McCullagh, et al.*
>
> *Text:* How can we be sure that the students attend to our lectures? How can we be sure that the student has understood a topic? These two questions were the holy grail of pedagogic research…….

Now for my next challenge, potentials for measuring knowledge, even artistic “genius”, like Bowie. I thought of a Bowie lyric:

> *“….Knowledge comes with death's release”* [2]

Better leave that one - for now.

4. Conclusion

The prototype investigates the difference between recall and acquisition of knowledge or cognition, in education. Future technology may be able to help

here. Intelligent glasses could have a clear role with measuring engagement between learner and teacher, but the application of hybrid EEG technology, while existing, is much more speculative at this stage. I'm sure the former will find use in immersive education very soon.

There is a spectrum between recall, cognition, knowledge and finally creative genius. In this paper the Eureka potential taps into cognition and the acquisition of knowledge.

The fictional prototype can serve to apply hybrid BCI technology into immersive education, much like a futuristic 1970s language laboratory, which used advances in magnetic tape recording to allow a student (and their instructor) to listen to their pronunciation of a foreign language. The prototype suggests similar feedback that can report on understanding, in a subject way.

The motivation for the work is the worry that in digital age education where storage of materials can comprise a link to the cloud, students utilize this learning paradigm and simply recall their work (for assessment) without sufficient understanding. Memorizing is necessary but not altogether sufficient for understanding.

Acknowledgements
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