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Uncertainty and engagement with learning games

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Abstract Uncertainty may be an important component of the motivation provided by learning games, especially when associated with gaming rather than learning. Three studies are reported that explore the influence of gaming uncertainty on engagement with computer-based learning games. In the first study, children (10–11 years) played a simple maths quiz. Participants chose their preferred reward for a correct answer prior to seeing each question. They could either receive a single point or toss an animated coin to receive 2 points for heads or none for tails. A preference for the uncertain option was revealed and this increased during the quiz. The second study explored the discourse around learning when pairs of participants (13–14 years) competed against the computer in a science quiz. Progress depended on the acquisition of facts but also on the outcomes of throwing dice. Discourse was characterised by a close intermingling of learning and gaming talk without salient problematic constructions regarding fairness when losing points due to gaming uncertainty. A final experiment explored whether, in this type of game, the uncertainty provided by the gaming component could influence players' affective response to the learning component. Electrodermal activity (EDA) of 16 adults was measured while they played the quiz with and without the element of chance provided by the dice. Results showed EDA when answering questions was increased by inclusion of gaming uncertainty. Findings are discussed in terms of the potential benefits of combining gaming uncertainty with learning and directions for further research in this area are outlined.

Keywords Uncertainty · Games · Motivation · Learning

Introduction

Games are frequently identified as a means to increase interest in the classroom (Bergin 1999), with educators being prompted to draw inspiration for new approaches from the intense engagement provided by computer gaming (e.g. Gee 2003). The processes by

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which such engagement occurs are not well understood, but may involve components of fantasy, challenge and curiosity (Malone 1981). The role of uncertainty has been relatively unexplored, despite uncertainty often being considered as an essential characteristic of any game (e.g. Juul 2003; Caillois 1961) and being identified by some (e.g. Loftus and Loftus 1983) as an important and pleasurable aspect of the challenge. Indeed, outcomes of many simple games (e.g. 'snakes and ladders') are purely chance-based and some element of randomness is frequently included in games as a means to provoke emotional responses such as surprise (Owen 2005).

The attractiveness of uncertainty has been well established by psychological experimentation (e.g. Atkinson 1957) that has shown moderate risk taking (50% chance) heightens motivation—a result that has been explained by theories of attribution (Weiner 1985) and intrinsic motivation (e.g. Csikszentmihalyi and Csikszentmihalyi 1988). More recent understanding of reward[1] involves consideration of 'wanting' and 'liking' as two dissociable components, with the wanting of a reward being coded by levels of dopamine release in mid brain areas (Berridge and Robinson 2003). The predictability of an outcome has been shown to influence this activity. In primates, it has been shown that maximum dopamine is released when the likelihood of receiving reward for success is about half way between totally unexpected and completely predictable, i.e. 50% likely (Fiorillo et al. 2003). Dopamine levels in this area of the human brain have been linked to our motivation to pursue a variety of pleasures, including sex, food, gambling (Elliot et al. 2000) and computer gaming (Koepp et al. 1998). The link between the predictability of an outcome and mid-brain dopamine activity is, therefore, helpful in explaining why humans are so attracted to games of chance (Shizgal and Arvanitogiannis 2003). Activity in this area has been studied non-invasively in humans during gaming using functional Magnetic Resonance Imaging (fMRI). These fMRI studies have shown that patterns of dopamine activity are predicted less by reward in 'real' absolute terms and seem more to do with winning the game. Activity can increase with reward size (Knutson et al. 2001) but, rather than being proportional to monetary reward, activation peaks at the same level for the best available outcome in different games (Nieuwenhuis et al. 2005). The complex relationship between reward and motivation is thus strongly mediated by context.

When uncertainty is encountered in more real life contexts, there are potentially more complex effects of context created by the social environment. These are illustrated by the way our natural attraction to uncertainty falls off when the task is perceived as educational. Students generally prefer low levels of academic uncertainty and choose problems well below moderate (<50%) challenge (Clifford 1988; Harter 1978). Interestingly, however, when the same tasks are presented as games, students will take greater risks (Clifford and Chou 1991). This may suggest that individuals can be deterred from tackling academic tasks with higher levels of uncertainty due to the implications of failure for social status and esteem. In terms of rehearsing knowledge and understanding, it is not necessarily a bad thing to be drawn towards areas where our ability requires only perfection through further practise. However, it could be argued that this may also reduce instances when outcomes are considerably better than might be expected, avoiding the stronger motivational signals that can be generated in the human reward system by these large and positive prediction errors.

The above arguments provide some theoretical basis for considering how the inclusion of a suitably integrated gaming component may enhance engagement with a learning context, i.e. through providing a source of uncertainty that is less associated with issues of

[1] Note that reward is being used here in the psychological sense, i.e. as a process, or set of processes, by which behaviour is reinforced.

social status. There are several issues here, however. Firstly, can the hypothesised attractiveness of the uncertainty provided by the gaming component survive in a learning context? The idea of losing marks due to total chance is very antithetical to the established educational philosophy of "reward consistency" and may provoke frustration and disappointment rather than interest. We attempt to answer this question in the first study reported here. If the inclusion of such uncertainty is preferred by learners, there are then questions about how it is represented in discourses around learning, that traditionally draw on concepts of fairness and just reward (e.g. OfSTED 2001). To address these, the second study was a field trial of a purpose-built science quiz game. The focus here was on how participants interacted with a learning context that included uncertainty provided by a gaming component, and in particular on how this component mediates the constructs around achievement and failure. More fundamentally, there remains the question of whether such components simply provide a 'sugar coating' for the sometimes bitter pill of learning, or whether they really can make the pill taste different. It is possible that any heightened emotional response remains restricted to the gaming components, and that learning processes themselves remain unaffected. Such considerations gave rise to our third study, in which we used measurement of EDA in adults in order to address the question: can the emotional response to a learning task be influenced by presenting it in a context that includes gaming uncertainty?

Study 1: quasi-experimental study of children's preference for gaming uncertainty

Method

Participants

Participants were 50 pupils (mean age 11 years 3 months 24 days, 27 males 23 females) from a primary school in Cyprus, drawn from two classes of 25 pupils each. The school was a typical inner-city primary school in the city of Lemesos and possessed a substantial ICT infrastructure. Formal permission for access to the school was provided by the Cyprus Ministry of Education and Culture. Parents of all participating children also provided informed consent prior to commencement of the study.

Task

Participants were asked to play a purpose-built computer quiz game in which they must answer whether a particular mathematical statement (e.g. $13 \times 42 = 564$) was true or false. However, before seeing each statement, they were asked to choose whether to receive it from Mr Certain or Mr Uncertain. Both would provide the same questions but, if a participant answered correctly, he/she would receive one point from Mr Certain and either zero points or two points from Mr Uncertain, depending on the toss of an animated coin. Answering a question incorrectly resulted in zero points for that question, whether provided by Mr Certain or Mr Uncertain. Participants were informed that they would be answering 30 mathematical questions and that the overall aim of the game was to collect as many points as possible. The design of the software ensured that each question was presented once, and the order of presentation was randomised for each participant. It was emphasised to the children that there was an equal chance of receiving 2 points or zero points from Mr Uncertain for a correct answer.

Procedure

Participants played the game individually, two at a time, in a quiet room on the school premises. The rules and aims of the game were explained and an opportunity was provided to ask questions, after which they were then allowed to begin playing immediately. The computer game was designed to record the order in which questions were presented and the responses of the children.

After all students had experienced the game, five girls and five boys were randomly selected from the sample to participate in semi-structured interviews. These participants were encouraged to discuss their emotional response and rationale for choosing Mr Uncertain or Mr Certain. Prompts included being asked to identify moments of strong feeling and being asked to reflect upon why they may have experienced these feelings.

Results and discussion

Out of a total possible score of 30, the mean of participants' total number of correct responses was 14.42 ($SD = 2.60$). This score was close to chance levels but, rather than suggesting random choices, probably indicates the success with which some of the questions exploited common mistakes made by pupils. For example, only 26% of participants succeeded in spotting that "5 + 30 = 150" was incorrect, reflecting young children's common tendency to confuse addition and multiplication signs.

Over the 50 participants, the mean percentage of occasions that Mr Uncertain was chosen was 61.4% ($SD = 6.9$) and analysis over all questions confirmed a statistically significant preference ($\chi^2(1) = 77.98, p < 0.0001$). Thirty of the 50 participants chose Mr Uncertain more times than Mr Certain, which demonstrated a statistically significant preference by participant ($\chi^2(1) = 4.26, p = 0.04$). The percentage of the sample choosing Mr Uncertain is shown as a function of the question number in Fig. 1, providing an indication of how preference for Mr Uncertain varied over the duration of the quiz. Linear regression analysis determined that question number was a significant predictor of preference from Mr Uncertain ($F(1,28) = 12.25$, $p = 0.002$) accounting for 30% of the variance.

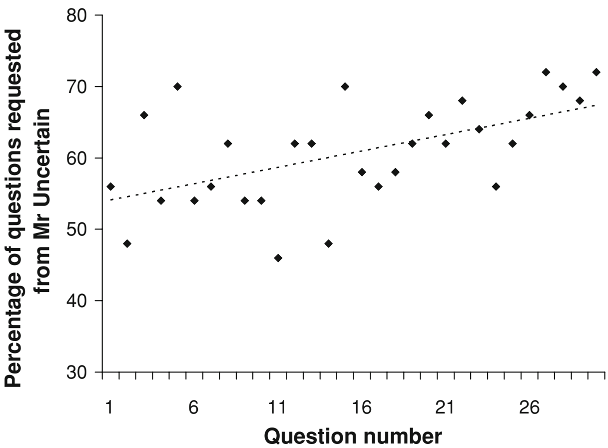

Fig. 1 The percentage of the sample requesting questions from Mr Uncertain is shown here as a function of question number (i.e. in terms of when it was presented). The graph shows how the preference for Mr Uncertain increased over the duration of the quiz

Of the 10 interviewees, behavioural results indicated that two of the students had chosen Mr Certain more frequently while the remaining eight had demonstrated some preference for Mr Uncertain. The two participants who had mostly chosen Mr Certain explained their preference in strategic terms:

> If I was lucky I would choose Mr Uncertain but if I was constantly not winning I would choose Mr Certain to get more points.

Explanations of the interviewees' preference for choosing Mr Uncertain were in more emotional terms. Interviews suggested that emotional responses to Mr Uncertain were more intense compared to Mr Certain, and these responses were characterised by a range of contrasting emotions. Sometime Mr Uncertain created frustration (quotes are translated from Greek):

> With Mr Uncertain…I was feeling very frustrated when the coin was tossed and I was getting no points.

However, as illustrated in the exchange below, this frustration was not necessarily describing an aversive feature of the game:

Researcher:	Were there instances that made you feel frustrated?
Participant:	Yes.
Researcher:	When?
Participant:	When I was getting zero points with Mr Uncertain. I knew my answer was correct but he was giving my no points sometimes.
Researcher:	Did that frustration make you want to quit the game?
Participant:	No…no…It made me want to try my luck with Mr Uncertain even more.

Overall, consistent with the experimental result, the attraction to Mr Uncertain did not appear dissipated by the disrupting effect he had on scores, even though this was sometimes a source of frustration. Participants also described Mr Uncertain as being more exciting and one, when asked to explain further, discussed how this compensated for the stress that was sometimes induced:

> Hm… Because you don't know what will happen and you want to win. You are stressed but if you win then you forget about that!

Generally, participants tended to explain their preference for Mr Uncertain in emotional terms such as "like" and "exciting", but one interesting quote from a participant trying to explain his preference for Mr Uncertain did so in terms of analogy:

> When I play football with my friends and kick the ball to score, I hope I'll manage to trick the defenders and the goal keeper and get the ball in the net. Whenever I kick I'm never sure that I will score. But I feel very happy when I score. If there isn't a goal keeper then everything is easier and I don't feel so excited when I score. I know that if I kick the ball at a specific point then it'll be a goal but if I miss then it won't.

This explanation seemed to resonate with the idea, put forward in the introduction to this report, that a learner can find a task more emotionally appealing when an element of uncertainty is introduced that is not wholly defined by the learner's own ability.

In summary, pupils demonstrated a preference for an element of gaming uncertainty in the mathematical quiz game, and this preference increased as they interacted with it. This study demonstrated children's preference for gaming uncertainty in a context that might be described as educational, at least in respect of the quiz assessing and providing feedback on their performance. However, the study was not designed to provide insight into how the uncertainty was interacting with processes related to learning or, indeed, whether any learning was occurring.

Study 2: classroom discourse around learning with gaming uncertainty

Study 1 indicated that young learners may enjoy having components of gaming uncertainty incorporated into an educational task, but how can this influence the associated discourse, particularly in regard to issues of fairness? The second study focused on the dialogue generated when pairs interacted with a learning game incorporating gaming uncertainty, to reveal more about the ways in which playful subversion of reward consistency can influence constructions around success and failure.

Method

Task

The task for this part of the investigation involved a purpose-built game called "Wipe Out". It was a quiz game testing factual knowledge relevant to Attainment Target 2 (Life Processes and Living Things) drawn from the UK National Curriculum for Science for Key Stage 3 (QCA 2000). Two animated dice were rolled and the combined score could be won if the subsequent multiple choice question was answered correctly. If this was achieved, there was the choice of rolling again or passing the dice to the opponent. Rolling carried an inherent risk because if a single one was rolled, all points for that turn were lost. Rolling a pair of ones resulted in a "wipe out", i.e. all points currently accumulated for the game were lost. Participants competed against an artificial opponent (i.e. the computer) in teams of pairs. The first to reach 100 (i.e. the team of two players or the artificial opponent) won the game. When either the participants or the computer answered a question incorrectly, or rolled a one, the sound of an audience sighing was heard. A 'wipe out' was accompanied by an explosion. On occasions when the team of players won, they were congratulated with a sound effect of loud applause. On occasions when the artificial opponent won the game, they received a loud 'raspberry' noise. Questions were randomly selected, with replacement, from a sample of 26. When questions were answered incorrectly by the participants, the correct answer was highlighted in red for 3 s. The participants could also learn from watching the artificial opponent answer questions, which it always did correctly. By attending carefully, participants could improve their subject knowledge and chances of winning. Although the computer never answered a question incorrectly, both the participants and the artificial opponent were vulnerable to bad fortune when rolling the dice. Thus, although participants could help themselves by improving their subject knowledge, the outcome of the game was still influenced strongly by chance. A screen shot from the quiz is shown in Fig. 2.

Participants

Participants were 20 pupils (6 male, 14 female, mean age 14 years 0 month 4 days) in a Year 9 science class (ages 13–14 years) in an urban comprehensive school in the South

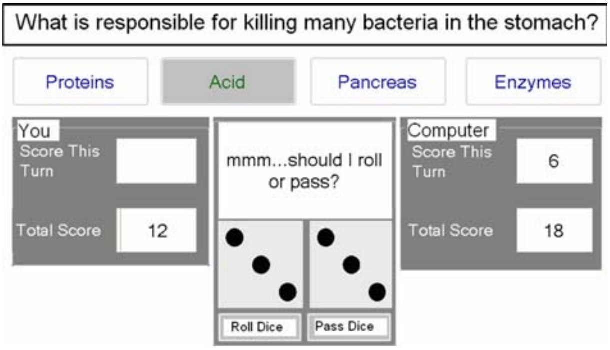

Fig. 2 Screen shot from "Wipe Out". The computer has (as always) chosen the correct answer but now appears to be vacillating over whether to the roll the dice again or pass them to the player

West of England. This was the lowest ability group of six sets of similar size. Prior consent from parents was provided in regard of all those participating in the research and additional parental consent was sought for participants who might be filmed.

Procedure

In a previous lesson, the class was asked to complete a pre-test consisting of a multiple choice questionnaire based on the 26 questions to be used in the game. At the beginning of the lesson when the game was to be played, participants were allocated by the teacher into same sex pairs according to her best judgment regarding the matching of ability, whilst also remaining mindful of friendships and the ability to work together. Four pairs were selected as being of mid range ability in relation to rest of the class and also in regard of researchers having received full consent regarding filming (two female: F1 and F2, and two male: M1 and M2). These four pairs were sat at computers behind which there was an unconcealed video camera arranged to record responses and dialogue during the game. A microphone from the video camera was placed between the pair, and an additional audio recorder (as back up) was connected to hands-free behind-the-ear microphones worn by the children. The task was introduced to the children as an opportunity to try a prototype of an educational game. Some very brief instructions were provided regarding the scoring system and how to initiate the game. The participants were then allowed to play the game for approximately 35 min.

Results and discussion

Means for pre and post test results, out of 26, were 10.58 ($SD = 2.95$) and 19.74 ($SD = 3.77$) respectively, with a paired comparison two-tailed t-test confirming a statistically significant difference between these means ($t = 8.87$, $p < 0.001$).

The audio recordings were transcribed and thematically analysed according to the categories shown in Table 1.

Three of the four pairs were very communicative during play. However, the F2 group spoke very quietly, with a lot of inaudible whispering to each other and giggling. Nevertheless, enough could be transcribed from this pair to confirm that roll/pass decisions and selections of answers were both being made by agreement, although with the minimum of

Table 1 Thematic categories used in the analysis of discourse in Study 2

Thematic category	Description	Example
Fairness	Talk explicitly or implicitly related to concepts of fairness	Explicit example: M2L: It's not fair M2R: It's a very good game but the computer knows a lot more that us M2L: It's not fair Implicit example: …why is the computer getting all the easy ones?
Learning talk	Talk relating to the answering of questions, discussion of concepts	M2L: depressant? I thought it was a stimulant M2R: it depresses you after a time…
Gaming talk	Talk related to game progress or strategy	F2L: yea…what shall we do? Pass or shall we roll? F2R: pass cos if we (roll) we'll loose all our points
Emotional response to events	Talk expressing an emotional response (celebratory, pleasure, disappointment etc.)	M1L: (tuts)…get two 1 s…take 14…go on get a one, go on get two 1 s…ohh M1R: Arh no…a nine M1L: go on go on-yeah-go on…yes I love it!
Emotional response to game in general	Instances when players reflected on how they were feeling about the game in general	F1L: It's just so tense it's so annoying

discussion (in extracts quoted from transcripts, F2L indicates the member of the second female F2 pair sitting on the left, with F2R sitting on the right, etc.):

F2L: what do plants need other than carbon…potassium?…pass?
F2R: that one
F2L: what shall we do?
F2R: fruit?
F2L: shall we pass?…roll? (Both whisper)
F2R: …I think…acid

However, the other three groups discussed these and many other issues more overtly. This discussion included explicit reference to issues of fairness, but these were never with regard to losing points on the throw of a dice. Claims of unfairness were chiefly restricted to complaints about the artificial opponent knowing the answers and implicit references that included suspicions that the opponent might be getting all the easy questions:

M2L: this isn't really a fair game
M2R: yea it's not because the computer knows the answers
M2R: …why is he, why is the computer getting all the easy ones?

The F1 pair also expressed fairness concerns about their opponent's level of knowledge and also when failing to answer a question correctly but, again, never expressed such concerns when losing points on the dice.

F1L: You should've went for that one
F1R: So unfair

F1L: (Sighs) ahhh
F1R: But it's not fair that he knows all the answers
F1L: So greedy
F1R: Urr hope you get a…zero

The last example was one of several that suggests the vulnerability of the artificial opponent to the throw of the dice was seen as a means of rebalancing any disparity of knowledge level between players and the artificial opponent. In this way, gaming uncertainty appeared to be a source of hope:

M2L: I want the computer to get a wipe out
M2R: get a one
M2L: because then we can actually get some points

The three pairs (M1, M2 and F1) each wished such ill fortune upon their opponent several times, the M1 pair as many as 12 times. There was also celebration when these wishes came true, resulting in a taunt from the F1 pair.

F1R: Hahaha—double one—what a loser

Although there were no references to fairness when players lost their points to the dice, this did produce considerable dismay and, at the beginning, a sense of surprise:

M1L: …you're joking…73 points (and) I got wiped out
M1R: this gonna be impossible…

In the light of such events, getting a question wrong was not seen as the worst thing possible:

M1L: that was out wasn't it…yea…I want them to get double 1 s now cos then that'd be alright… I've got to get this…annelid?
M1R: You never got it wrong mmm…oh that wasn't a…thought (that) was it
M1L: that wasn't a wipe out—we didn't loose anything

All pairs indulged in large amounts of gaming and learning talk and these sometimes occurred closely together within the same exchange:

M1L: that's 10 points I'm not passing that off
M1R: yes yes yes…a 2 part…ar no
M1L: no way…got a 2 part body 4 pairs of legs
M1R: but no wings?
M1L: …got to be because 4 × 2 is 8 and spiders have 8 legs and spiders arachnid. I rock.
M1R: come on…yes
M1L: we're gonna win, we're gonna win…what is responsible for killing many bacteria
M1R: acid
M1R and M1L together: yeah…come on!

As in the previous example, there were several examples of team spirit in the face of threat from the opponent, with shared decision making and mutual exhortation to each other to remember certain facts:

F2R: yea…remember that in case we get it again…and remember that.
F2L: ah

F2R: …bones is that?
F2L: yea…what shall we do? Pass or shall we roll?
F2R: pass cos if we (roll) we'll loose all our points

From the outset, there seemed a sincere determination to beat the artificial opponent expressed by all players:

M2R: this game farts when it wins
M2L: it shouldn't be able to win. Oh yea definitely I'm going to play this game and I'm going to make sure we win… Does protein (reading)…

However, as the game progressed, the frequency and force of these expressions of determination increased as all players began to personalise their opponent as a male human. This development was illustrated well in these five separate extracts taken in sequence from M1L:

M1L: roll or pass…hmm 31…I don't trust it
M1L: oh f*** look look…it's way ahead of us now
M1L: ok…right it's his go…is it a him or a her? I wonder
M1L: …I don't trust you…(to computer)
M1L: …you lost you suck (sings song by Eminem) it's starch I know…

This mounting aggressive competitiveness was not restricted to the male pairs:

F1L: Look he's on 54 now, he'll lose his points
F2R: Come on (name of F1L)…kill him
F2L: Oww—I'm gonna kill him (laughs)

Misfortune was generally attributed to bad luck and talked about (as in success) in gaming terms:

M2L: agh—we got obliterated. Completely annoying, we haven't had any good rolls
M2R: no

But success was still celebrated vigorously, and often in words that expressed a triumph due to ability (and in the case of pairs F1 and M1 with singing and dancing):

F1R: We're just too good—I can't believe we're doing good

which seemed also to increase the determination to win again:

M2L: roll, pass pass…yay…105
M2R: 105
M2L: we beat him
M2R: 105…we beat him, we beat him, yea
M2L: I'll roll first get a roll…pass…he never passes it…wait…errr…I couldn't think of it
M2R: agh
M2L: we're going to have another bad game aren't we?
M2R: bad now, I'm a bad loser

Spontaneous expressions of anxiety pointed to a build up of tension in the game:

F2L: You sure?
F2R: I'm scared but yea
F2L: It's just so tense it's so annoying

M2R: agh…
M2L: agh…agh…agh…this is really “agh agh” (laughs)

Participants were highly engaged throughout the session, restarting a new game very quickly after completing the previous one. The words “fun” and “annoying” were commonly used to describe the game when participants reflected at the end of the session. This seemed to suggest a compulsive element to participants’ motivation to engage with the game, illustrated in this spontaneous exchange between girls who had been playing for 30 min and had just succeeded in winning against the artificial opponent:

F1R: Shall we play again?
F1L: So annoying…
F1R: Don’t mind…shall we?
F1L: Yeah, roll the dice…

In summary, learning was achieved in terms of being able to correctly answer questions that had previously been incorrectly answered. There was a close intermingling of a game talk and learning talk during the game. Fairness was discussed with respect to differences in player–opponent ability but not with respect to losses due to chance (i.e. gaming uncertainty). Such losses produced significant emotional responses but did not appear to deter the players. Indeed, the gaming element appeared to offer hopeful encouragement as a potential means by which to compensate for disparities in player–opponent ability level. During playing of the game, the artificial opponent became personified as something of a “hate figure”. The game appeared to provide high levels of motivation, but was described as both fun and annoying echoing a mild form of the dissociation between motivational elements of appetite (wanting) and consumption (liking) discussed above.

Study 3: influence of gaming uncertainty on physiological response of adults

In games such as Wipe Out, learning and gaming components are experienced in close sequence to each other, but remain essentially separated in time. It is possible that any gaming-related emotional response is restricted to responses to the gaming elements themselves and does not spill over into those events related to formal learning outcomes. However, high learning scores, the emotionality of participants’ responses and the close intermingling of gaming and learning talk in Study 2 suggested this might not be the case. That is, it was thought that the element of gaming uncertainty in Wipe Out might be influencing affective response during answering of questions and receiving of feedback. Given that declarative memory formation can be enhanced by emotional context (e.g. Brierley et al. 2007), this is a potentially important issue for those designing learning games. To investigate this issue further, an experiment was devised in which the electrodermal activity (EDA) of adults was measured when responding to answering the quiz questions, with and without gaming uncertainty.

Method

Task and conditions

There were two conditions of gaming uncertainty, each using a modification of game that was investigated in Study 2. The ‘gaming’ condition exposed participants to gaming uncertainty, and here the quiz game proceeded as in Study 2, beginning again when a winner was declared. In the ‘no gaming’ condition, gaming uncertainty was removed and here the quiz game was identical in all respects except that:

– The dice throw always produced a double three (so no penalties for throwing a one).
– Turns were automatically alternated between the player and the computer.
– There was no final score for winning, the game went on continuously.

In both versions, there was a 3.5 s pause after the rolling of the dice, i.e. just before the question was presented. During this pause, the word “REST” appeared on the screen. This allowed the affective response to the throw of the dice to dissipate before measuring the response to answering the question.

Participants

Participants were 16 volunteer post-graduate students (7 females, 9 males, mean age 28 years 1 month 28 days).

Procedure

Participants had two electrodes fastened comfortably with velcro straps to the tips of their middle and index finger. Electrode gel was used to improve contact. Participants were provided with instructions on how to play the game and were allowed to experience both conditions, each for about 2 min, using content designed for primary school children. This allowed them to practise the structure and rules of the game. Participants then experienced 10 min of quiz game in each of the two conditions in almost immediate succession. Questions were those used in Study 2, but these were divided into two equal subsets to be used in the two conditions. Combinations of question subset and condition were permutated to minimize presentation order effects.

Data was sampled at 100 Hz and changes in EDA were recorded using a high pass filter (0.05 Hz). The mouse used by participants when operating the experimental software was specially modified to also produce a logic pulse to the EDA recording equipment when pressed. The experimenter also marked the data, as it was being recorded, with notes about whether the computer or participant was playing, when the 3.5 s rest period had begun, whether the answer was correct or not and comments regarding unusual movements that might influence the recording of the EDA (e.g. sneezing, coughing, scratching). Additionally, the software was set to record a range of events during the game, which allowed checking of the experimenters’ annotation. Informal comments about the two conditions were solicited from each participant at the end of their session.

Results

Means, standard deviations and sample numbers for scores of correct and incorrect answers achieved by participants are provided in Table 2.

Inspection of the EDA data for the two conditions of gaming uncertainty suggested an increased response for answering questions when in the gaming condition. This is typified by the difference in the exemplar plots of EDA shown in Fig. 3. This difference was confirmed by quantitative analysis.

For the quantitative analysis, a window of analysis was used that began 3.5 s after the appearance of the word “rest” and extended until the beginning of the next roll of the dice,

Table 2 Means, standard deviations and sample numbers for scores of correct and incorrect answers achieved by participants in Study 2 in the two conditions of gaming uncertainty (gaming, no gaming)

	Mean	*SD*	*N*
Correct answer			
Gaming	12.93	4.72	203
No gaming	16.94	3.70	271
Incorrect answer			
Gaming	4.71	2.61	81
No gaming	5.69	2.98	91

up until a maximum of 25 s. The range-corrected peak response during this window was recorded. Means and standard deviations of changes in range-corrected EDA, measured in siemens (mho) when participants were answering correctly and incorrectly are provided in Table 3 for the two conditions of gaming uncertainty.

Distributions of individuals' mean EDA responses are illustrated by box plot in Fig. 4. Within-subjects analysis showed main effects of gaming uncertainty ($F(1,16) = 11.12$, $p = 0.004$) and correctness of answer ($F(1,16) = 23.84$, $p < 0.001$) with no statistically significant interaction between gaming uncertainty and correctness of answer ($F(1,16) = 1.23$, $p = 0.283$).

There was no correlation (as calculated by Spearman's rho) between EDA when answering questions and the points available for a correct answer (i.e. previous dice score) for either correctly answered questions ($r_s(203) = -0.031$, $p = 0.660$) or incorrectly answered questions ($r_s(81) = 0.097$, $p = 0.391$). A total of 9 (out of 293) measurements had to be discounted from this part of the analysis due to difficulty in identifying the score with which they were associated.

Discussion

The inclusion of an element of gaming uncertainty appeared to raise the EDA of the adult participants when answering questions that were intended to support their learning. This implies that the affective response to learning itself may be influenced by elements of gaming uncertainty, even when these are combined in a fairly superficial and sequential manner. In the no gaming condition, the lack of a gaming element allowed a greater number of questions to be answered within the time limit. This may have increased habituation and suppressed EDA response, at least for well-rehearsed questions which participants were confident they could answer correctly. However, this would not explain the increase for questions answered incorrectly, which occurred in equal numbers in both conditions and were generally encountered at the beginning of each condition, before participants had been able to learn from their mistakes.

This study presented adults with the same quiz questions that had been given to children in the previous study, but the number and spread of incorrect responses still demonstrated a good range of ability within the sample. However, in terms of relating this study to the two that preceded it, some care must still be taken in assuming results from adults can be used to construct ideas about children's cognitive processes. There is some evidence that physiological responses, as measured by EDA, are similar in adults and children in contexts such as arousal due to emotive pictures (McManis et al. 2001) whilst imaging evidence suggests developmental differences in the neural process of decision making in

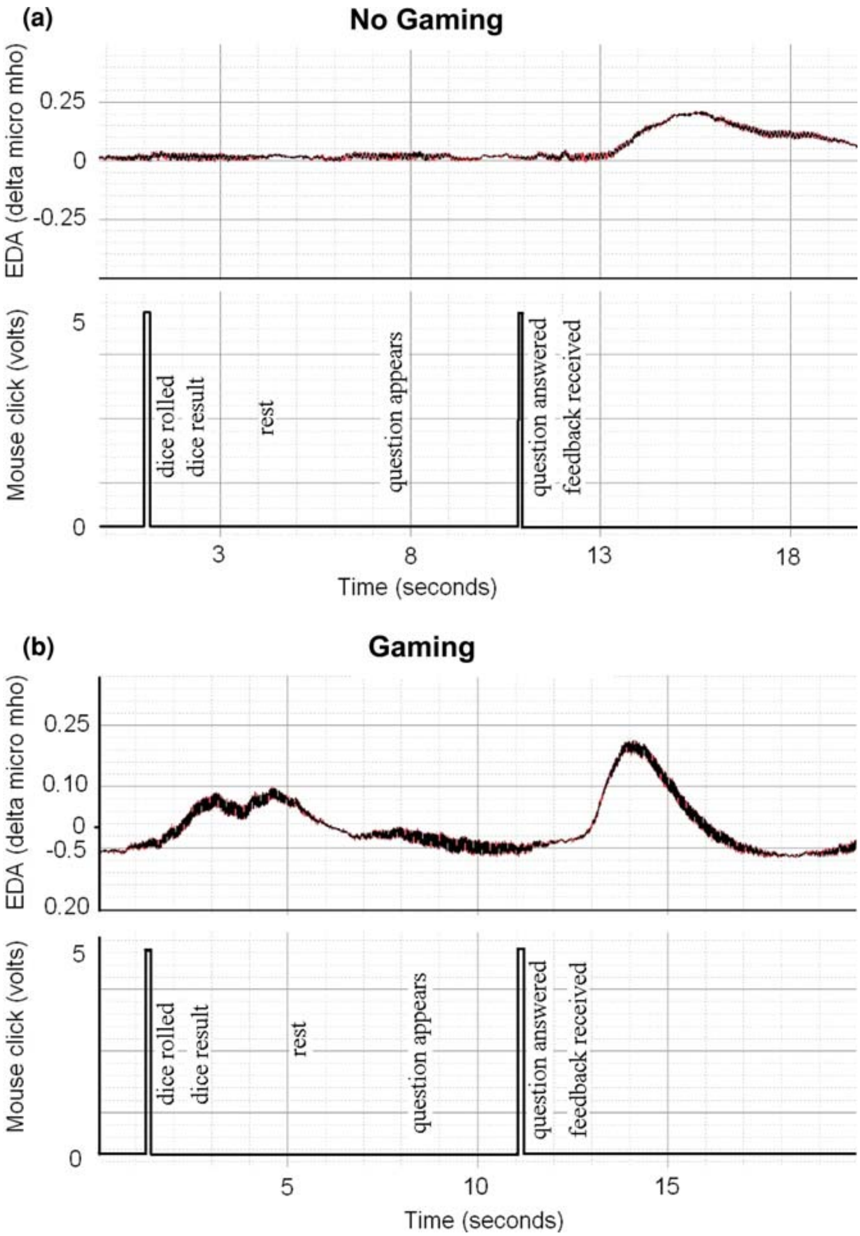

Fig. 3 (**a**) The affective response of a participant in the 'no gaming' condition. Here, the participant first watched a dice roll which was 'fixed' to provide a double three. There is no detectable response to this very predictable event. A question was then presented to which the participant responded incorrectly. The impact of answering the question and receiving the feedback did produce an increase in EDA, slightly delayed by 2–3 s due to the physiological processes involved. (**b**) The response of the same participant when answering a question incorrectly in the "gaming" condition. Here, the rolling of the dice, with its unpredictable outcome, did generate an EDA response but, more interestingly, also appeared to increase the intensity of response to answering and receiving feedback for the subsequent question

Table 3 Means and standard deviations of changes in range-corrected EDA (in mho) for the two conditions of gaming uncertainty (gaming, no gaming), for questions answered correctly and incorrectly

	Mean	*SD*
Correct answer		
Gaming	0.261	0.122
No gaming	0.197	0.101
Incorrect answer		
Gaming	0.399	0.151
No gaming	0.275	0.120

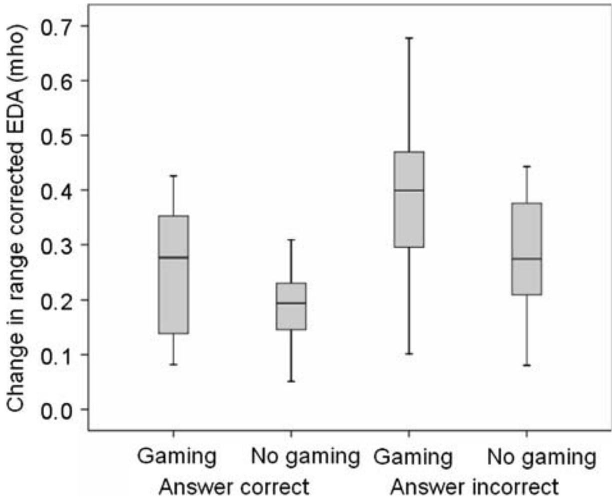

Fig. 4 Box plots of participants' average changes in range-corrected EDA in siemens (mho) during response to correctly and incorrectly answered questions for the two conditions of gaming uncertainty (gaming and no gaming)

uncertainty, including greater aversion to negative feedback amongst children (van Leijenhorst et al. 2006). It would, therefore, be useful to repeat this third study using child participants. However, computer gaming holds a special place in children's preferred pursuits. Therefore, one might hypothesise that, if differences do exist, physiological response to elements of gaming uncertainty and associated elevation of response to learning elements, might be greater in children than adults.

Overall discussion and conclusions

The first study demonstrated a clear preference of primary school children for the incorporation of gaming uncertainty in a mathematical quiz. In Study 2, significant levels of factual memorising amongst children (aged 13–14) were achieved using a computer quiz game based on gaming uncertainty. Analysis of discourse around the game revealed how traditional notions of classroom fairness can become subverted by elements of gaming uncertainty, in ways associated with potentially positive outcomes for the emotional engagement of participants. In Study 3, it was shown that the affective response of adults to learning tasks incorporated in such games was higher when elements of gaming uncertainty were included, suggesting that engagement with the learning, rather than just the game, is enhanced.

The first of our studies was originally provoked by an emerging understanding of the motivational value of uncertainty, and how this relates to changes in dopamine release in the human reward system. The preference for gaming uncertainty shown by children in the first study, and the tendency for this to increase with repetition of the task, concur with current neuropsychological concepts predicting physiological multiplication of incentive value with repeated exposure (Tindell et al. 2005). However, these mechanisms, which may also support increased motivation to approach the component of gaming uncertainty in Study 3, do not explain the increased affective response when interacting with the subsequent educational components several seconds later. Understanding increases in excitement that continue over such time scales may need to include consideration of hormones such as testosterone and cortisol, that often increase in concentration during competition (Erickson et al. 2003; Frye et al. 2002). Although such ideas are speculative, there is currently considerable interest in the potential for collaborative research between neuroscience and education (e.g. Howard-Jones 2007; OECD 2007), and the authors tentatively suggest that learning games may be one area that would benefit from such initiatives.

Taken together, our results suggest that gaming uncertainty can transform the emotional experience of learning. This may improve engagement and, more importantly, may also improve encoding and later recall. It has been reported elsewhere that memory for items encoded in a positive emotional context is improved, compared to neutral or negative contexts (e.g. Erk et al. 2003). However, the results presented here stop short of providing any indication of possible memory effects of gaming uncertainty. The experiment reported in Study 3 was not designed to assess learning and no conclusions can be reached about how any enhancement of emotional response may have influenced memory. Also, although error rates were similar with and without the gaming element, inferences about memory efficiency based on such error rates would need to take into account the distribution of these errors during the 10 min period and the frequency of repetition of individual stimuli. All this would make for an overly complex analysis from which it would be difficult to draw conclusions. However, it is suggested that specially designed studies to investigate the effect of gaming uncertainty on memory could provide further valuable insights for education.

It should be noted that, for experimental expediency, all three studies used computer-based tasks and focused on learning in simple terms (i.e. basic maths and factual recall), although dialogue recorded in the second study did provide examples of how the science quiz task used in the second and third study could provoke occasional exploration of concepts between collaborators. However, the strategy of increasing emotional engagement through the inclusion of gaming uncertainty might also be effective in non-technological contexts and other areas of learning, including those that require deeper levels of processing and understanding. Future investigations might valuably explore the effect of gaming uncertainty in these contexts.

Excessive use of gaming uncertainty to engage children with learning might raise ethical questions about longer term effects. Some association has been reported between problematic playing of non-monetary computer games and problematic gambling, although this is not necessarily causal (Johansson and Gotestam 2004; Griffiths 2005a). In general, however, computer games have not been linked to the development of pathologies or serious health risks (Griffiths 2005b). Given that the incidence of computer game addiction is itself very low (Griffiths and Davies 2005), it seems unlikely that even excessive use of games such as "Wipe Out" could lead to problematic gambling behaviour in later life.

In conclusion, we have highlighted uncertainty as one way in which games may succeed in engaging their players, by drawing on concepts arising from current understanding of the human reward system. We have shown that combining an element of gaming uncertainty with a learning task can improve its attractiveness and also, perhaps more significantly, influence the affective response of the learner to this task. Inclusion of gaming uncertainty is contrary to prevailing notions of reward consistency, but our results suggest children may find this less problematic than might be expected.

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