Students' experiences of learning mathematics through games design

Gallear, W., Lameras, P. & Stewart, C.

Original citation & hyperlink:
Gallear, W, Lameras, P & Stewart, C 2020, Students' experiences of learning mathematics through games design in ME Auer & T Tsiatsos (eds), Internet of Things, Infrastructures and Mobile Applications: Proceedings of the 13th International Conference on Interactive Mobile Communication Technologies and Learning, held on October 31- November 01, 2019 in Thessaloniki, Greece. 1 edn, Advances in Intelligent Systems and Computing, Springer, pp. 547-558, 13th International Conference on Interactive Mobile Communication Technologies and Learning, Thessaloniki, Greece, 31/10/19.
https://dx.doi.org/10.1007/978-3-030-49932-7_52

DOI 10.1007/978-3-030-49932-7_52
ISSN 2194-5357

Publisher: Springer

The final publication is available at Springer via http://dx.doi.org/10.1007/978-3-030-49932-7_52

Students' experiences of learning mathematics through games design

Wayne Gallear, Petros Lameras, Craig Stewart
Coventry University, Coventry, UK
{gallearw, p.lameras, craig.stewart}@coventry.ac.uk;

Abstract-This research explored the serendipitous learning of mathematics in a group of Further Education students, after mathematics elements were embedded into the lessons. Data was gathered from students studying a Computer Games Design course. The data was gathered using both quantitative and qualitative methods. The findings indicated that students' view of mathematics had changed to a more positive one in a positive direction and some students learned mathematics during this process. The data analysis showed has shown that stealth embedding mathematics within a games design unit helped to deal with barriers to engaging and learning mathematics.

Keywords— Serious games; education; serendipitous learning, stealth teaching, eLearning.

1. Introduction

This paper is about research into students making a computer game with a mathematics element in it and how they experience this and what affect making a computer game has on their mathematics ability. In particular FE students (17 to 20 yrs. old) in an English FE college based in a relatively poor socio-economic demographic area. The researcher has witnessed the energy and enthusiasm with which a typical student will play computer games and simultaneously the lack of energy and distinct lack of motivation to engage in any form of college related study, in particular the study of mathematics. This is backed up by Pouyamanesh and Firoozeh who observed that "Students, who believe that their previous failures were because of their disabilities in school assignments learning, probably don't expect to be successful in same assignments, so unlikely they will try more." [9]. David C. Geary argues that "innumeracy is more common than illiteracy and many adults are functionally innumerate when they leave school" [2]. This links with Professor Wolfs report that states that in the UK "50% of students obtain a GCSE grade C (or above)" [1]. In 2017 this pass mark was just below 60% [8]. This paper is more focused on the phenomenographic aspects of the research but the quantitative research is mentioned and referred to as well. The rational and methodology of how this approached is discussed as well and the details of the results are mentioned. This research can be used to affect how modern pedagogies with the use of appropriate technologies (in this case games engines) can be used to effectively enhance students learning.

2. Background research

This paper is a summary of 5+ years of research and as such it is impossible to put all that research within this paper. Mathematics and computer games design and phenomenography are the core elements of this research. As stated earlier the 40% of students are failing to pass mathematics. How can technology be used within this research experiment? To recap, this research is about dealing with students who have had a negative view of mathematics and about how we can get a mind change. Gamification was first discussed in 2002 by Nick Pelling. It is now a global subject and is not just about education, it is used in marketing, politics and even healthcare. Games Design itself has been found to be a useful teaching pedagogy because games design is inherently a creative process the student engages with. Students can in Games Design creatively solve problems. Yu-Sien Lin [3] argues that "Humanistic scholars also see creativity as the natural urge of individuals to develop, extend, ex-press and activate their capacities". Gamification is adding game elements to an activity, usually to make the activity more engaging. This research is more than whether mathematics can be learned as a side effect of making a game, a student is intrinsically motivated to play a computer game.

3. Methodology

3.1 Introduction

The initial ideas and hypothesis to this research all took place in early 2014. The pilot study took place in late 2014 and the results were published in the paper "Serendipitous learning & serious games: A Pilot Study" [6]. The pilot study indicated that students were learning mathematics, however more research was needed. From that research this research took place. These research questions started this research.

How do students approach and feel making a game with mathematics embedded within it? !
Can students learn mathematics whilst creating a computer game with mathematics ! elements in it? !

For the purpose of this paper a sample of students was taken who were doing a games design course in academic year 2017/18 (n = 32 students in all, all students turned 18 during this study) and from this group n=13 students, (2 female, 11 males) were selected. These 13 students all struggled with probability (taken from initial mathematics assessment data), however all had passed GCSE mathematics at school. The students are further split into two groups, Group A and Group B. All the students use college PC's with 'GameMaker' software installed. These students were part of the larger games design course, who were all doing the same two assignments. These students were not treated any differently than the other students. These students where

not taught by the researcher but by a colleague. The students were using the same software and the same techniques to create both games. The development process is identical for both. Therefore, any mathematics learned during the process will be the same. However, in one game mathematics is an added element of the game (they make a card game so probability), this element is missing in the other game that is been developed. It is the effect of this element that is being measured not the process of game development.

3.2 Description of methodology and data collection

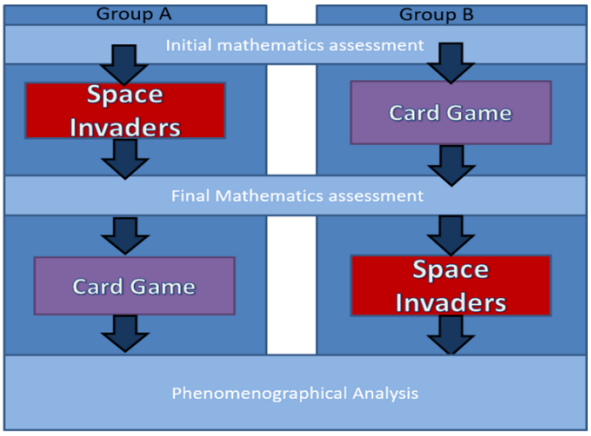

Fig 1. Methodology process

Fig 1 shows process. Students are split into 2 groups, both are given an initial mathematics assessment then one group does the card game then the other does the space invaders game. They are then given another mathematics assessment. After both groups have completed both games the researcher performs the interviews and the phenomenographicanalysis

As discussed researchers have found some students have a negative experience of mathematics, even fear. If, during the games design process of making a game with mathematics within it, a student has a 'mind change' from a bad experience to a good experience, how can we evaluate this? This is why phenomenography is used. Phenomenography gets a second order perspective of the student's experience of making a game with mathematics within it. A series of open ended questions were asked on a one to one basis just after they completed their game. These questions were open ended and additional questions were asked if needed, to clarify points if things were not clear. Why (and how) do some students learn to enjoy mathematics and develop mathematics skills whilst developing serious games? The questions students were asked started as general questions about what they thought of the assignments, and gradually changed to more focused questions about the types of games, then to specific question about mathematics elements within the games. The questions are not

closed and rigidly structured. Further questions were asked sometimes depending on answers and how the student was engaging in the process. The semi structured questions started with general questions that asked the students how they felt about both assignments (an assignment is the designing and testing of a game). They are open and give the students an opportunity to open up about the game process in a general sense. Next the focus changed to questions about making the card game and making the space invaders game. Questions like 'How did you feel when you realised you were doing a card game?' From this the researcher can see a preference. One student said "I think I was kind of relieved because I could ease into it rather than going straight into the harder one."(Student 8). They also asked if they had learned anything. Most students answered about the game engine (GameMaker) and how they had learned that. Then they were asked if they had learned mathematics in both games and asked to reflect on their own mathematics knowledge to see if they had learned anything. About 30 questions were asked with more added if felt appropriate.

A student's skill at the beginning of the process, before they create a computer game with a mathematics element within, versus the mathematical skill of the same student after they have created the game. Then by measuring the difference between these two values can be analysed to see if "a student learn mathematics". This quantitate approach will check to see if these students do actually learn mathematics. However, we need to consider that students may learn mathematics by simply just creating any computer game, regardless of whether it has a specific mathematics element in it. So how can that be accounted for? As mentioned earlier the 13 students are making 2 games, a space invader game and card game. The control experiment was the space invaders game. This game didn't have a direct mathematics element within it. The card game (called "mathematics experiment" for this study) has a specific mathematics element, probability in this case. The same tests were taken by the student before and after creating the game to check the student's mathematics skills. The end results could then be checked against the results from the students who created the game with the mathematics elements within it.

4. Results

4.1 Phenomenographic results

After the interviews had been concluded, the data (called scripts) is analysed to study the students' experiences. Alsop and Tompset explain that "Each account is one description of one experience, which is limited by what was perceived by the individual at the time and considered to be relevant on this one occasion." [4] So the first process of phenomenography is to analyse these experiences. Booth says "The researcher is expected to 'step back consciously from her [sic] own experience of the phenomena and use it only to illuminate ways in which others are talking of it, handling it, experiencing it, and understanding it" [5] So it's not enough just to read, the researcher needs to maintain an unbiased approach. An approach of structured reading is used. Each script is analyzed. "The researcher tries to carry out the analysis for one theme or aspect at a time, simultaneously looking for overall patterns formed by the various

aspects and how these aspects are related to one another" [5] So looking for these themes or conceptions is the key to the phenomenography. These themes or conceptions form what is known as the categories of description. These categories are logically separate but are hierarchically linked to each other. These themes or conceptions are how the student engages with the games design process. The variation between the categories is also important. The researcher is looking for 'meaning' from all this data processing. The outcome will show how the varying ways of experiencing a computer game with mathematics in it are seen by students.

Fig 2: Categories of description found from analysis

Fig 6 shows the categories of description that were found.

1. Creative Driven
2. Experiential Driven
3. Collaborative Driven
4. Coding Driven

4.1.1 Creative Driven

This least developed category about the creative inspiration the students had first before they even started to make this game. The student stands back from the game development process and looks at the big picture of what they want. They look at the visual imagery they want and how it could be applied. This comes from games they have played and the visual themes they wish to apply. They focus on creating story boards, background stories and do the art work for the game.

“I quite enjoyed the art aspect of making the game I enjoyed making all the sprites and making the backgrounds and the card back I started with a concept of what I wanted you to look like I took inspiration from Hearthstone I looked at pub type card games I wanted it to look fancy and Regal that was quite interesting” (Student 1).

When they make their games they refer to their creative to picture constantly. Some students can be perfectionists and if they don’t get something that matches this picture they can struggle and get frustrated and can get stuck not move forward. So this picture can be quite rigid. They look at the game development process as a part of a big picture. This also means that the mathematics element (within the card game) has to fit into this picture. These students tended not to like the coding elements and struggled with it. They also are less independent, they tend to need more support and direction with the game development.

4.1.2 Experiential Driven

In this category it’s all about how the student approaches the game creation process. They start with a creative picture as above but that is not their focus. These students want to get on with the nuts and bolts of the development. So these students learn through doing, in an experiential learning approach. David Kolb describes how knowledge is gained first-hand, instead of hearing or reading about others' experiences. The game they have can be different from initial ideas but is generally what they first visualized. These students have a go, then when they get stuck they ask for help.

“I fiddled about with it until I got it right” (student 13). This student had an experiential learning approach initially to the game creation process.” Another said “I generally just wanted to play about with it and figure about with it until I got it right” (student 10). This student had an experiential learning approach to the game creation process. “I like the visual aspects relating the Nintendo universe to this card game I like that so the sprites. I really like creating all the different visuals with inspiration from the Nintendo universe and I thought that that turned out well I sort of kinda like doing the coding and stuff and seen it how we all work together I have an analytical mind so I enjoyed that seeing how things piece together and work and all that so yeah it was quite fun.” (Student 2). This student when the script was first read felt like a creative, but they are not. Notice how they enjoyed putting it all together, that is where the passion is. The students were actively reflecting on their personal learning journey. This breaks away from the traditional academic process of gaining dry subject knowledge. This approach is about an iterative cycle of learning a skill then applying *it.*

4.1.3 Collaborative Driven

This is about working with others to create the game. It is hierarchically lower than experiential but has the significant difference that they work with others. It’s about team work and also about breaking the task up with other and putting focus on specific areas then sharing with a small group how they solved a particular games design issue they found. They tend not to seek help from the lecturer they support each other and rarely

ask for help directly. These students choose to work together with others after asking the lecturer. They work best with their friends.

“I pretty much just watched your videos then me, Fred and Bod worked together to help each other to figure out the bits that weren't explained” In this it’s Collaborative, the 3 students all watched a tutorial and then helped each other figure out how to make a game. These are students 6, 7 and 8 who all make the space invaders game.

4.1.4 Coding Driven

In this category it’s more focused on the coding aspect of the game. How the mechanics work within the game. The student looks at how things work in a game and how to implement them. It’s hieratically linked to experiential learning and connected to it but with the focus on coding. It is also linked with how the students implement the mathematic side of game. These are independent students and rarely ask for support.

They may have a picture of what they want but what they create can be very different from their initial ideas. “I learned a lot about coding and scripts in the game, more about implementing scripts into the game itself more than anything else.” Another said “Whilst making this game I learnt a lot of new code like an AI that followed you when you entered a certain area.” And another “The game was surprisingly easier than expected, with more mathematics and code involved I expected it to be much more challenging. I began to actually enjoy the coding at some level as it can make the game very cool.” Saying as well “I was kind of scared at first I had no idea the coding and I didn't know how to start it but after some research I figured it out and got it going. And I enjoyed the coding.” (Student 4)

These are the categories of description found in the students doing both games. It must be noticed that all students did both games, the card and space invaders games. The mathematics tests were after the sample had made the first game which was half way through the academic year. These categories are logically separate and are hierarchically linked. These categories are the perceived focus the students took. Another way of looking at them is the student’s passion or focus. Some students had more of passion for the creative point of view, some focused on the experience of creating the game (trial and error), some like working in a team and some connected with the coding more. The 13 students all fitted in one or more of these categories. Most just had one focus. These categories all develop from each other. The least evolved categories been Creative, then the experiential one is next which has elements of the creative. The collaborative is even more involved and had elements of the two previous categories. The most evolved is the coding that has elements of all the categories with it.

4.2.1 Dimensions of variation

The categories of description are about the students focus or what they did. The next step is to look at the role that technology has on a student, the role of a lecturer, the role mathematics has and the role the game has. How do these vary from category to category?

4.2.2 Role of the Lecturer – reduce and get quotation

The lecturer is part of the environment of this game development cycle. The role they play depends on the student's need. In terms of the creative driven students these need a lot of direction and support from the lecturer. The student's big picture about what the game looks like can be quite rigid and can prevent them from developing the game sometimes. They get stuck and can find the coding and card aspect a challenge to implement. Experiential driven students have a creative picture but are more focused on experiment and on experiencing the process of making the game. They prefer to try first then ask questions later. The lecturer does not need to support them as much. Collaborative driven students are even more independent and the lecturer may not support this group of student who are working collaboratively. It must be pointed out these students are all individually making their own game but work collaboratively to figure out the mechanics of the game design. Coding driven students are the most independent and tend to work on their own with a very fluid design that changes constantly as they develop as coders and as the game develops. They rarely need support from a lecturer.

4.2.3 Role of the Technology

How the students engage with and what type of technology they focus on depends on what drives them (what category they fit in). Creative driven students focus on technology that helps them develop their inner picture of what the game should look like. Such as Photoshop / sprite creator software etc. In the game engine itself (GameMaker in this instance), they focus on the sprites and animation. Experiential driven & Collaborative driven students use GameMaker from the get go. They try things out first then put sprites in the coding. They refer to the games design You Tube tutorial created by the lecturer and in the case of collaborative learning, try different approaches and then discuss the outcome. Coding driven students use GameMaker from the get go but focus on the coding aspect part of the engine (GM Script, which is like C#). They read forums and research online how to do certain things and are constantly improving their code.

4.2.4 Role of the Game idea

With Creative driven students, the game idea is the big picture they see. It can be rigidly adhered to even if it's not practically implementable. These students can be perfectionists and need help softening this rigid idea. Experimental driven and Collaborative driven have the big picture and do their best to adhere to it but are more flexible in their approach than their creative driven cousins. The game they create looks similar to their big picture with some differences. The collaboratively driven students' games may look similar in look and feel as they have worked together. Coding driven students have big a picture and start with this but as they develop their game they are evolving it and improving it, so the final game may be better than the original idea or very different. It will however be the most fully functioning game of all the games produced.

4.2.5 Role of mathematics / cards element

Creative driven students may have a card game idea, they may have played a card game like 'hearthstone' or another card game. These students tend to struggle implementing the card game concept. Experimentally driven students have card idea and picture but try experimenting with different ideas until they find something that works. Collaboratively driven students have a card game idea and picture but try experimenting with different ideas until they find something that works. They share this with their small group and tend to go with the best results. They use each other's best results. Coding driven these independent students have a picture and do research in how to implement and code this. Looking on forums and experimenting with other code samples. When they find something that works they implement it.

4.3 Outcome space

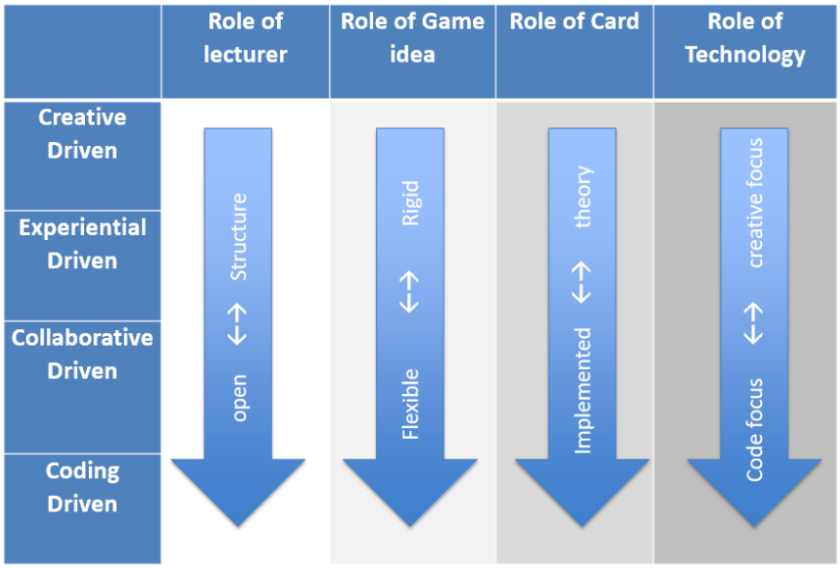

Fig 3: Outcome space

In fig 3 the arrows show how students engage with the games design process. On the left hand side are listed the categories of description and across the top are the Dimensions of variation. So how the lecturer responds to a student varies according to what motivates them. Some students are creative driven only. They need more structure in their leaning, stick to this creative picture more rigidly and have a theory and struggle to implement it and creatively focused throughout the game design students. These students tend to struggle more, however the learners that fit in the coding driven category are more open, as in they don't need as much structure and help and are open

to new ideas (the word open on Fig 3), they are more flexible with their creative picture and adapt to their game and can implement and focus on the coding more naturally.

Student 12 fits in the creatively driven category. When asked "Are you quite Arty and creative?" she answered "Yes I like to think I am the King, Queen and Jack they were fun to do the art for them." When asked about coding she answered "I think I was kind of overwhelmed by the card game because there was a lot of coding which I really don't know how to do I was very relieved at the end because I finally got it done I'm more or less got it working."

4.2 T-tests results

It must be stated that quantitative analysis works better on larger studies. Qualitative analysis, phenomenography in this instance, works well on smaller studies. This must be taken into account with the results for the quantitative data. However the results from the quantitative analysis are important indicators. As stated earlier n=13 students were chosen for this study out of a pool of 32 students who were also making the same games.

	GCSE	Game	first test	second test	dif
Student 1	a	Card	61%	73%	12%
Student 2	c	Card	39%	59%	20%
Student 3	b	Card	35%	47%	12%
Student 4	c	Card	45%	63%	18%
Student 5	c	invaders	24%	29%	6%
Student 6	b	invaders	69%	75%	6%
Student 7	c	invaders	45%	53%	8%
Student 8	c	invaders	57%	61%	4%
Student 9	c	Card	43%	57%	14%
Student 10	c	Card	25%	31%	6%
Student 11	c	invaders	65%	53%	-12%
Student 12	c	Card	76%	80%	4%
Student 13	c	invaders	53%	55%	2%

Fig 4: quantitate data from tests.

As seen in fig 4, 7 students did the card game and 6 did the space invaders game. The data above shows the results from the first (or initial) mathematics test and second mathematics test. As can be seen, most students the difference (shown as 'dif' column) is show a positive difference (shown in 'dif' column). In other words most got a higher percentage in the second test. Average mathematics difference for card game is 12%. Average mathematics difference for space invader game is 2%. Looking at averages we get a 10% increase in test scores in the card game sample.

3 Discussion

Student 12 focused and enjoyed the creative elements and didn't enjoy the coding aspect. All the students started with a 'big picture' of what the game should look like, but she stayed there and rigidly stuck with this picture. She needed support and help in making the game. She spend much more time using creative technology and a limited amount of time using the coding. Student 12 had a 4% measurable mathematics increase. Now looking at student 2 who firmly fits in the coding driven category. She had a 'big picture' as well but evolved and experimented with code and worked with others and eventually enjoyed and focused on the coding side of things. When asked about how she made the game she answered. "So to start with I got the sprites of the objects out the way so I created those then I did some research the statements the functions how scripting works and then after that created it piecemeal". When asked about the coding "I was kind of scared at first I had no idea the coding and I didn't know how to start it but after some research I figured it out and got it going and I enjoyed the coding"(student 2). This student freely admitted they were "scared of coding" but later stated "I enjoyed the coding". They had a picture but were flexible with it, they used creative software but move onto the coding tools. They had some support and structure at first but then came up with their own structure and ideas. This student had the greatest percentage increase between first and second mathematics assessments of 20%.

Using these students as examples, both had a 'big picture' of the game. One however moved beyond that and experimented with some ideas and developed into a coder. Fig 7 shows the outcome space from the phenomenographic study that took place. Students who do best are those that embrace coding. They start with a creative picture and get support and structure from the lecturer but are flexible and open to learn and embrace new skills like coding and reflect on their leaning. Putting the focus back on student 2 who had the greatest measurable mathematics increase. When asked earlier did you learn anything the answer was "I don't think so no"
When asked at the end of the interview when asked "Do you think doing this card game that helps you learn mathematics?"

They answered "Yes I think it has helped it really helped me get my brain going" Shows that the student was largely unaware of leaning skills. However, at the end of the interview they did feel they learned some mathematics.

4 Conclusion

This mixed method study has found that students experience and engage with a game with a mathematics element is different ways.
From a quantitative standpoint the data seem to indicate that students making a card game are learning mathematics. Average mathematics difference for card game is 12% whilst average mathematics difference for space invader game is 2%. T-Test result of 0.02 supports this as well ($0.02 < 0.05$ so null hypothesis holds). However, its ($n=13$) a small sample size.

The Phenomenographic results showed that students who embrace the coding fully, who are open and reflect on their experiences enjoy coding (and mathematics) and have got better math test averages. The challenge is how to adapt this information into

practical teaching pedagogies that embrace the facts found in this study. As stated in the discussion the students can learn in a serendipitous way. The technology acts as a platform for this. The students are immersed within the process of game development and this links with the student own passion for playing games. The students without realizing it are tapping into their own passion for playing and making computer games to overcome a distaste or even a fear of doing mathematics.

5 References

[1] ! Wolf, 2011 “Review of Vocational Education – The Wolf Report” available from https://www.gov.uk/government/publications/review-of-vocational-education-the-wolf-report

[2] ! Geary D 2013 “Early Foundations for Mathematics Learning and Their Relations to Learning Disabilities” available from Sage publications at http://cdp.sagepub.com/content/22/1/23.full.pdf+html

[3] ! Yu-Sien Lin “Fostering Creativity through Education-A Conceptual Framework of Creative Pedagogy” available online from http://www.scirp.org/Journal/PaperDownload.aspx?paperID=6710

[4] ! Alsop G and Tompset T C(2006) Making sense of ‘pure’ phenomenography in information and communication technology in education, ALT-J, 14:3, 241-259, DOI: 10.1080/09687760600837058

[5] ! Booth, S. (1997) On phenomenography, learning and teaching, Higher Education Research and Development, 16, 135–157.

[6] ! Limberg, Louise. (2000). Phenomenography: A relational approach to research on information needs, seeking and use. The New Review of Information Behavior Research. 1. 51-67.

[7] ! Gallear W, Lameras P and Stewart C, "Serendipitous learning & serious games: A Pilot Study," 2014 International Conference on Interactive Mobile Communication Technologies and Learning (IMCL2014), Thessaloniki, 2014, pp. 247-251.

[8] ! Schools Week. (2019). *GCSE Results 2017: Mathematics*. [online] Available at: https://schoolsweek.co.uk/gcse-results-2017-mathematics/ [Accessed 29 Jun. 2019].

[9] ! Pouyamanesh, J. and Firoozeh, L. (2012). “Compared the Learning Outcomes of Students with Math in High and Low Frustration Tolerance.” Available at: https://www.sciencedirect.com/science/article/pii/S187704281301731X