Wicked Problems as a Context for Probability Education

Theodosia Prodromou
University of New England
tprodrom@une.edu.au

Chronis Kynigos
National and Kapodistrian University of Athens
kynigos@eds.uoa.gr

This study focuses on pre-service teachers' experimentation with a game-modding process in a constructionist setting whilst they experimented with randomness embedded in wider socio-scientific issues that call for decision making under uncertainty. In this process, participants created 39 different game mods. Our observations of the participants while they worked on the mods suggest that grappling with wicked problems while using digital socio-scientific games can offer new contexts for harnessing causality to facilitate students' meaning-making for randomness embedded in such contexts. In order to bridge the deterministic and the stochastic in wicked problems, the students transfer agency to specially designed numerical consequences of choices, by inserting proportional thinking, game theory, and probability.

Introduction

Human brains revolt at the idea of randomness. Just learning the concept of randomness seems to be difficult (Prodromou, 2008; Prodromou & Pratt, 2013; Pratt & Noss, 2002). Piaget's seminal work (Piaget & Inhelder, 1975) reported how the organism initially fail to apply operational thinking to the task of constructing meaning for random phenomena. In this sense, Piaget offers us a first hint that we only begin to gain some mastery over the stochastic after we learn how to exploit our well-established appreciation of the deterministic. Prodromou (2008) studied students aged 14–15 who made sense of distribution, adopting a range of causal meanings for the variation observed in the basketball computer simulation and in the graphs generated by the simulation. The carefully designed computer simulations offered ways for harnessing causality to facilitate students' meaning making for variation in distributions of data, much as, according to Piaget, the organism invents, much later, probability as a means of operationalising the stochastic. The basketball simulation developed helped shed light on how students at one level let go of the deterministic whilst at the same time re-applying those ideas in new ways to construct meanings about probability distribution. In this study, instead of using digital media for experimentation, we used a constructionist setting where experimentation is part of a modding process for a game.

The game-modding environment provokes deterministic meanings that we might be able to harness in a productive way while a) students experiment safely with randomness, that b) is situated in wider socio-scientific issues and our everyday lives, making it more interesting and relevant. We study participants' meanings of randomness that are both embedded and generated in a real context, illustrating explicitly the way they made decisions under uncertainty when grappling with complex and wicked problems. We conjecture that grappling with wicked problems while using digital socio-scientific games might offer new contexts for harnessing causality to facilitate students' meaning-making for randomness embedded and generated in such contexts and enhance the development of language that is used when making decisions about wicked problems. Such understandings and language pervade almost everything we do and directly inform the way we conduct our everyday lives.

Theoretical Background

The use of a constructionist setting for experimentation in the modding process fosters: 1) the learning of concepts related to randomness, and 2) meaning making of the difficult concepts of randomness that are embedded in a wider socio-scientific issues. In each case, the role of ideas about randomness and probability in the thinking process was that they would be the

2022. N. Fitzallen, C. Murphy, V. Hatisaru, & N. Maher (Eds.), *Mathematical confluences and journeys* (Proceedings of the 44th Annual Conference of the Mathematics Education Research Group of Australasia, July 3–7), pp. 450–457. Launceston: MERGA.

ticket to find a solution to a problem or to investigate an open problem thoroughly and comprehensively, even if it has no solution. Mathematics is the mechanism to pose or solve problems. There has been very little study, however, of understanding probabilistic ideas and ideas about randomness and putting them to use in the context of grappling with wicked problems and in the frame of a post-normal science epistemology. Increasingly, the real problems in our society are complex and there is an increased awareness that such complexity, like that observed in environmental and sustainability problems, may lead to powerlessness, paralysis, and apathy if learning is not scaffolded to generate a sense of agency (Kollmuss & Agyeman 2002). How can we infuse such an element in education? How can we help students reduce confusion and stress about issues surrounding them and appreciate that mathematical thinking can be useful and relevant in such contexts?

In the study reported in this paper, we engaged in design research aiming to engage students (or prospective teachers in the role of students) with such issues by using a digital socio-scientific game, an online environment that was used for participants to approach randomness anew, with a disposition to re-structure (Wilensky, 2010). The aim was to explore the ways in which randomness is conceptualised in education in the quest to make it more attractive and afford meaning making to students and aid in grappling with complex problems. We approach meaning making of randomness from a social and situated perspective, whilst studying the dynamic interactions of participants, though participants' relations, their interactions with the game, mathematical concepts and everyday knowledge or everyday events that involve problems including "wicked problems" (Rittel & Webber, 1973), which are described as dysfunctionalities within a complex system (Conklin, 2005). The term "wicked problems" (WPs) was coined by Rittel (1972) to describe design problems in the domain of social planning and a particularly challenging type of ill-structured problem (Rittel & Webber, 1973). WPs involve a high degree of uncertainty, lack definite right or wrong solutions, are highly contextualised, involve political considerations, and are characterised by a high level of inherent ambiguity and normative conflict.

Wicked Problems

Wicked problems (WPs) are characterised by the lack of clarity in both their aims and solutions, and they deal with the complex, fuzzy, multifaceted, contentious issues in both big projects (e.g., urban development) and small (e.g., a healthy personal diet). Wicked problems are difficult to contain and structure, are interconnected and interdependent, and are ill-defined and dynamic, as their parameters are continually in flux (Rittel & Webber, 1973; Coyne, 2005). Unlike with mathematical problems, whose consequences are minimal, when dealing with wicked problems, the effects of a planner's actions can matter a great deal to the people who are affected by those actions, and planners can be held liable for the consequences of the solutions they generate. Faced with such problems, individuals often feel overwhelmed, develop denial and resignation, followed by inertia due to a sense of determinism, which permeates societies (Hulme, 2009; Lazarus, 2009). Yet wicked problems need action at many levels, which requires taking risks and acknowledging the randomness inherent in the problem. For the individual, it is important to engage in becoming knowledgeable on the problem and to also engage in actions. In the context of personal diet, which is used by the games in this study, individuals' actions can include planning their own individual diet; maintaining their individual diet; and challenging their own beliefs and eating habits. Additional complexity is added by interest not only in a personally healthy diet but also in contributing to community decisions—whether a classroom (as with the participants of this study) or some larger community of interest—about diet that engage with the wickedness of planning a diet, as well as the wickedness in designing and developing a game that educates people about diet.

The design of digital educational resources for fostering new ideas in collective design and meaning making in a mathematically rich area of study like probability and randomness, brings the study of students' grappling with a WP in the design of a diet to the fore. Similarly, the modding brings the study of WPs in the mod to the fore. In this study, we looked at the process of modding collaboratively, focusing on their attempt to grapple with WPs and develop personal agency, action competence, and meaning making about concepts of randomness. In this context randomness (mathematics) and thinking about randomness (mathematical thinking) will not resolve the problem nor will it help define the problem clearly, but it may help engagement with the problem, development of meaning, and understanding of subproblems and issues.

A paradigm shift is needed to move from solving well-defined siloed problems to a post-normal science approach that grapples with complex real-world problems (Lehtonen et al., 2019). So, consider a transformational stance to schooling in an attempt to integrate such a post-normal science approach in teaching and learning, addressing and perceiving students as young citizens (McLaren, 2013). Consider the challenge of harnessing wicked-problem education to become syntonic and integrated with the innovative educational push towards cultivating the eight key competences for lifelong learning (European Commission, Directorate-General for Education, Youth, Sport and Culture, 2019).

Method

In this study, our 10 participants worked on joint design of games in the ChoiCo online digital environment, forming different *communities of interest* (CoI)—a group of practitioners from diverse disciplinary and/or professional backgrounds who engage in that activity collaboratively within their own communities of practice to design digital educational resources (Fischer, 2001)—in different contexts. The ten participating CoI members were practitioners in different levels of education (from primary to tertiary education) who specialised in primary education, physical education, and/or English or German education. This diversity in knowledge domains, perspectives, and cultures was meant to enhance the CoI's creative potential. We engaged in design research aiming to engage students (or prospective teachers in the role of students) with such issues by using a digital socio-scientific game. Using the ChoiCo game-authoring system, we designed a game for the students to work with. The game was concerned with healthy diet, which we perceived to be a WP in a domain that was already familiar to the students.

The ChoiCo environment consists of Play Mode and Design Mode, so the users could alternate between playing and designing, changing the content as well as the rules of the game. In play mode, the player made selections from among many options. Each choice had consequences for a number of game attributes and none of the choices had only positive or only negative consequences. For example, Food choices (Figure 1), the game discussed in this article, offers different food choices such as "hamburger", "vegetables", "chicken", etc. The player makes a food selection and observes the effect of the choice on four attributes (nutritional_Value, Kilos, Pleasure, and Health). The player tries to keep these variables within set limits for as long as possible. In design mode, the user can either design a new game from scratch or modify an existing game. We embedded mathematics in the game by carefully designing numerical consequences, and by inserting proportional thinking, game theory and probability.

Data and Analytical Approach

Our data were the online discussions of the participants and their written reflections when they used ChoiCo to reason about randomness and implement randomness in the design of a novel game that simulated a realistic everyday situation in which people make decisions about their food preferences. We developed two similar games in ChoiCo that provided several different options of food to eat (Figure 1). One was fully deterministic; the other included use of a random number generator. The aim of both games is to make food choices and keep the game attributes “Nutritional Value”, “Kilos”, “Pleasure” and “Health” within specific numerical values. In play mode, the participants played the two games and wrote down their food choices, the game values, and their justifications for the strategies they used to stay in game as long as possible, referring to the numerical values of the game attributes “Nutritional Value”, “Kilos”, “Pleasure” and “Health”.

Figure 1. ChoiCo game.

The participants reasoned about whether the notion of randomness was embedded in the game and compared the two games in terms of their results (food choices and game values) and the notion of randomness involved in the game. We expected that the absence of realism in the game would trigger participants to modify the game or design new games that simulate a more realistic situation where people make decisions about their daily diet. The modding process was divided into three main phases: “Play-Modify-Create”. In the modding process of the ChoiCo game, creativity manifested as the result of using the idea of randomness to either create a realistic context of something new (a novel game related to diet) from something that did not exist before or modify the game in the ChoiCo environment, which supports students’ autonomy, risk taking, freedom, flexibility, and playful learning.

Results

This study shows that in participants’ engagement in the game modding process, they used the idea of randomness in the process of modding, which in turn acted as a scaffolding for the development of some important understandings about randomness. Four episodes were selected to illustrate the implemented alterations through four distinctive phases, which are used to structure the story of how the relationship between causality and variation shifted as users moved through these phases: A) Playing, experimenting; B) Changes related to the elements of the game, such as the rules, codes, and values of the game; C) Application of algorithmic building and modifying the code of the logical expressions; D) Creating a new game.

The first episode involved two Col members: Amanda and Sophie, both master of primary education students. In this episode, there was a mod created that introduced changes to the elements of the original game. Amanda and Sophie played both games and initially engaged with observing the implementation of randomness in the second:

> Sophie: Game one provides no randomness. This is because the values of each food choice remain the same and can be replicated with each turn.”

> Amanda intervenes: I believe the algorithm provides messages based on set game/food choice values, for example, if the pleasure value is too high or kilo value is too low. You can stay longer in the game by checking the game values of each food choice before selecting to ensure it contributes positively to your score…

Their attention focused on game two and Amanda continued:

> Amanda: The concepts of chance included in game two is randomness, or pseudo randomness as it is generated by the software. This can be seen in Table 4, where the pleasure value for each food item has a range and the software will select a number at random within that range. This means the results cannot be predicted or replicated.
>
> Sophie: If the focus was simply on comparing the food choices and their values (not cumulative values), then this game could be used to demonstrate randomness to students. By playing the game and recording their food choices and values, they could see that in game 2 the same choices do not replicate the same scores and therefore are random. Alternatives to this, that may be clearer for students to comprehend include rolling the dice, random draws, and the random number function in Excel. It should be noted that randomness is also produced by each player's preference and food selection, however, as the algorithm prefers healthy choices to keep you in the game. This is somewhat limited and not such a clear example of randomness.
>
> Amanda: The updated game, I uploaded increases the range of pleasure values to include both positive and negative for each food choice. This will enable students to see a wider range of variables amongst the pleasure scores, making it clearer to Year 5 students to investigate this concept of randomness.

The next episode, Episode 2, lasted four days and the participants were four CoI members: Sue and Sarah, preservice primary teachers, and Charles and Tess, in-service secondary teachers. All of them are studying for the Master of Education degree. They discussed the concepts of chance embedded in game one:

> Charles: In game one, on my first attempt I clicked [on] hamburger and died immediately. The concept of randomness was displayed here as I made a random choice … students can see the values for each food, and after playing several times, discover that alternating between *always food* and *sometimes food* keeps them in the game longer.

As Charles began to explore the effect of making different food choices causing variation directly on the food values, it appeared that the students felt that they were not able to make their choices randomly because of the pop-out messages. The discussion continued considering other features of the game.

> Sue: Although it is true that values had been allocated by the programmer with certain amounts of randomness, if students are able to see the values, chance does not come into play. Discussions surrounding bias could be developed when analyzing this activity. During play, pop-outs say things like "You might have health issues" and "Start eating healthier meals."
>
> Tara: I also believe the game can be more realistic by removing all the nutritional information from the Point Information box. In real life, we cannot analyse the factors of nutritional value, health, kilos, and pleasure for every single item that we eat. We can make predictions about the outcomes based on what we know is healthy versus unhealthy and what we enjoy, but the actual outcome is out of our control to an extent. The game coder can implement pseudo randomness in the game by hiding the information in the Point Information table so that it is not visible to the player.
>
> Sue: In general, eating food in real life often does not come with detailed nutrition information so the game could also hide parts of the Point Information table so that the user has to make their selection using their prior knowledge rather than rely on the data in the table.

In their attempt to make the game more realistic, the participants removed the pop-out messages and hid the game values. Gradually, the discussion became more focused on Game 2 and was oriented towards making decisions about the embedded randomness and cross-curriculum issues such as nutrition. Participants used different strategies to discern randomness. For example, when this CoI group discussed randomness embedded in pleasure, Charles made the same food choices in Game 1 and Game 2 to observe the different game values when randomness was introduced in Game 2. It appeared that Charles explicitly recognized that pleasure from food might be chosen randomly from the values within a predefined range. This insight was accompanied by the acknowledgment that the repetition of the same choices did in fact show variability:

> Sarah: In Game 2, a truer element of randomness is evident in the points allocated for pleasure which are randomly generated with a particular pre-defined range. Making a choice contains an element of chance, but students maintain relative control as they can look at the range and make appropriate choices. We ran the same pattern of 10 foods through both Games 1 and 2 (vegetables, legumes, kebab, eggs, pasta, diary, fish, chicken, ice cream, fruit).
>
> Charles: I played Game 2 three times. Each time the pleasure values were different despite making exactly the same food choices, yet all other values remained the same. Making these comparisons is a good way of demonstrating randomness to students.

A special feature of this stage is the CoI members attempt to make the game more realistic by changing the elements of the original game. They discussed the attributes' values that had been allocated by the programmer with certain random ranges.

> Sue: It is not however, particularly realistic. To make the game more realistic we made some changes to the game. Firstly, it was important to allocate randomness to health as well as pleasure. While fruit is obviously a healthy food, it would not be healthy for someone to make almost all their diet fruit, so it is appropriate to introduce randomness into health values. Rather than having a set number such as a 10 for diary, I allocated a random range between 5 and 15. And have repeated this range of 10 for each item. Another to which I assigned random vales is nutrition. Using vegetables as an example, it is more realistic to have a random value assigned to a vegetable because in reality, not all vegetables are nutritionally alike. Starchy potatoes are a lot less nutritious than kale. Also, I have raised the starting level of health to 40. Starting the game by eating a hamburger should not cause immediate death.

Students applied algorithmic concepts both in the database (variables, types) and in the block-based editors creating conditional statements, logical expressions, etc. The modified games' rules appeared to be created by logical statements that progressively were expressed by logarithmic building. For instance, in episode three, another group, Yeeka and Engel, both special education master's students, modified the game and wrote:

> The game was modified to make gameplay more engaging for diverse students, with each game being different due to random variation without being overly unpredictable. Pseudo-randomness was added to the Nutritional Value to simulate real-life variations from different food preparation methods and freshness and choice of ingredients. Some of the food variables were altered to balance out the positive/negative effects more realistically. The additional Hydration Value—based on the water content of foods—and choices of Water and Juice also add realism and complexity to the game. The difficulty of the game increases as play advances due to higher minimum limits set for Health, Hydration and Pleasure values.

As we evidenced above, due to the random variation inherent in the game, randomness was implemented to other variables (Nutritional Value, Kilos, and Health) and new variables also created (Figure 2) to illustrate real-life variations when making a food selection. They mapped these expressions to the relevant block-based code.

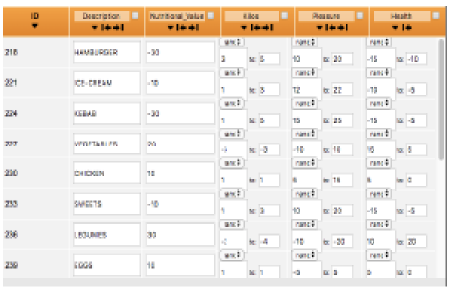

Figure 2. Nutritional Value, Kilos and Health Variables.

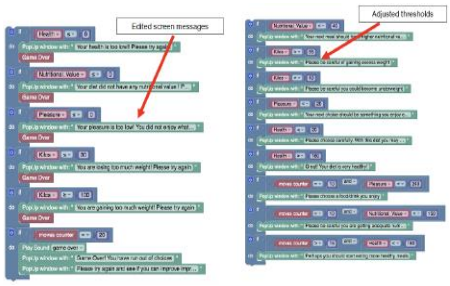

Figure 3. Conditional expressions and new rules.

The participants studied and edited the logical expressions in the code to create new rules and also edited the screen messages to make the behaviour of the game more realistic (Figure 3). Eight of the 39 different mods created had new attributes. In two of them, the participants also added new layers and designed a new setting for the story. For instance, the fourth episode, involves a CoI of three, Anna, Judy, and Angus, bachelor of secondary mathematics education students, who designed a new game that included recommend servings of food items per day versus its calories and nutritional value. As Anna wrote,

> We include in our game recommended serving per day of any food item in view of its total energy count and nutritive value to measure a well-balanced ratio of the essential nutrients: carbohydrates, fat, protein, minerals, and vitamins in food or diet. Users' choices provide students with feedback about making healthier choices that can affect their body and overall functioning.

Another CoI group (Mike and John, Bachelor of Primary Education students) created a different map-based game scene in which they included restaurants with their food menus, and the varieties of food they eat at home.

> John: While the knowledge of each food can give rise to certain likelihoods over others within each variable, nothing is certain, and thus the values of each food within the game for each variable need to reflect this notion of variation and randomness to food and nutrition in real life … hamburgers are unhealthy but only from fast food restaurants. They can be very healthy if made at home. Thus, the health and nutrition value scores need to reflect this variation.

Conclusions

Randomness was embedded in the variables of the ChoiCo game through a mechanism that can be seen as an example of what Papert refers to as a quasi-concrete object (Turkle & Papert, 1991), in the sense that the virtual objects can be manipulated in ways akin to how we learn about material objects through their use. We were exploiting here an affordance of computational objects to facilitate an intuitive connection to abstract formalisms (e.g., risk, handling randomness) in ways that are not available through conventional approaches. In our game, formal mathematical ideas of socio-scientific issues are instantiated as on-screen (Papert, 1996) quasi-concrete (Turkle & Papert, 1991) objects, virtual artefacts that can be manipulated on screen like material objects and experienced as concrete and tangible (Turkle & Papert, 1991). Those quasi-concrete materials foster participants' risk taking and experimentation (Calder, 2011), allowing space for students to explore the essential nutrients, carbohydrates, fat, protein, minerals, and vitamins in food or diet, make decisions about their food choices, whilst taking into consideration the impact of food on their health, weight, and pleasure. Participants experienced randomness through game modding (instead of stochastic experiments, e.g., rolling dice, etc.) and they seemed to harness causality (Prodromou, 2008) in order to re-construct a game that embodied realistic elements, based on testable conjectures, which sensitised the CoI's appreciation of meanings as they shifted between randomness, concepts of chance, and knowledge about nutrition and healthy eating. The aforementioned shift amongst those different domains, indicates the immediate need for a paradigm shift, from solving well-defined siloed problems to solving wicked problems in an attempt to integrate a transformational stance to teaching and learning.

References

Calder, N. (2011). *Processing mathematics through digital technologies: The primary years*. Sense Publishers.

Conklin, J. (2005). *Dialogue mapping: Building shared understanding of wicked problems*. Wiley.

Coyne, R. (2005) Wicked problems revisited. *Design Studies*, *26*, 5–17. http://dx.doi.org/10.1016/j.destud.2004.06.005

European Commission, Directorate-General for Education, Youth, Sport and Culture. (2019). *Key competences for lifelong learning*. Publications Office. https://data.europa.eu/doi/10.2766/291008

Fischer, G. (2001). Communities of interest: Learning through the interaction of multiple knowledge systems. In Proceedings of the 24th Annual Information Systems Research Seminar in Scandinavia (IRIS'24), Ulvik, Norway. Department of Information Science. http://l3d.cs.colorado.edu/~gerhard/papers/iris24.pdf

Hulme, M. (2009). *Why we disagree about climate change: Understanding controversy, inaction and opportunity*. Cambridge University Press.

Kollmuss, A., & Agyeman J. (2002). Mind the gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research, 8*(3), 239–260.

Lazarus, R. (2009). Super wicked problems and climate change: Restraining the present to liberate the future. *Cornell Law Review. 94*(5), 1153–1233.

Lehtonen, A., Salonen, A. O., & Cantell, H. (2019). Climate change education: A new approach for a world of wicked problems. In *Sustainability, human well-being, and the future of education* (pp. 339–374). Palgrave Macmillan.

McLaren, L. (2013). Educating for complexities: Using future focus education to approach the wicked problem of climate change. http://researcharchive.vuw.ac.nz/handle/10063/3348

Papert, S. (1996). *The connected family. Bridging the digital generation gap*. Longstreet Press.

Piaget, J., & Inhelder, B. (1975). *The origin of the idea of chance in children*. (L. Leake, P. Burrell, & H. D. Fishbein, Trans.). Norton. [Original work published in 1951]

Pratt, D., & Noss, R. (2002). The microevolution of mathematical nkowledge: The case of randomness. *The Journal of The Learning Sciences, 11*(4), 453–488. Lawrence Erlbaum Associates

Prodromou, T. (2008). *Connecting thinking about distribution*. [Doctoral dissertation, University of Warwick, United Kingdom].

Prodromou, T., & Pratt, D. (2013). Making sense of stochastic variation and causality in a virtual environment. *Technology, Knowledge and Learning, 18*(3), 121–147.

Rittel, H. (1972).On the planning crisis: Systems analysis of the first and second generations. *Bedriftsøkonomen*, *8*, 390–396.

Rittel, H. W., & Webber M. W. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, *4*,155–169.

Turkle, S., & Papert, S. (1991). Epistemological pluralism and the revaluation of the concrete. In I. Harel & S. Papert (Eds.), *Constructivism* (pp. 161–192). Ablex.

Wilensky, U. (2010). Restructurations: Reformulations of knowledge disciplines through new representational forms. In J. Clayson, & I. Kallas (Eds.), *Proceedings of the constructionism 2010 conference*. Paris, France: Comenius University, Bratislava, Slovenia: Library and Publishing Centre.