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Nikolay Panayotov
Iain Donald
Ruth Falconer
Vera Kempe

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Linking Gameplay Metrics to Computational Thinking

Nikolay Panayotov, Iain Donald, Ruth Falconer and Vera Kempe
Abertay University, Dundee, UK
n.panayotov@abertay.ac.uk
i.donald@abertay.ac.uk
r.falconer@abertay.ac.uk
v.kempe@abertay.ac.uk
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Abstract: Computational thinking (CT) is considered to be a fundamental skill underlying not only programming ability, but also an entire array of computational problem-solving competencies in a data-driven world. The need for accessible and engaging educational tools for CT has recently been acknowledged as significant by educational authorities. Glitchspace is a first-person puzzle game where the player has to manipulate objects in the game world through a visual programming interface in order to escape the cybermaze and win. The game received critical acclaim for its innovative and engaging gameplay, including a British Academy Scotland Award (BAFTA). However, the educational potential of Glitchspace in relation to CT ability has not been sufficiently explored. As success at playing the game relies on the players' ability to program the game world to suit their goals, it is hypothesised that common measurements of CT will positively correlate with game ability (measured by game metrics, such as completion times and number of failed attempts of various sub-tasks). We propose to develop methodologies to explore the relationship between gameplay behaviour and computational problem-solving ability in the game Glitchspace. Such methodologies will allow researchers to investigate which game mechanics elicit and promote CT in a reliable and measurable way. The outcome of this research will be of great value to instructional designers seeking to leverage games for CT education, as well as learning game analysts seeking to map gameplay behaviour to learning outcomes.

Keywords: game analytics, computational thinking, computer science education, game-based learning, programming ability, game metrics

1. Background

1.1 Computational Thinking

The most influential definition of computational thinking (CT) comes from Wing (2006) who argued that it "involves solving problems, designing systems, and understanding human behavior [sic], by drawing on the concepts fundamental to computer science". CT is clearly related to programming ability; however, it has been argued that CT comprises a more general approach to problem solving that leverages the abundance of data and computing power available in the present day (Bocconi et al, 2016). These kinds of arguments have encouraged a wave of curriculum reform, especially in relation to incorporating computing technology, and in particular CT, throughout diverse subject areas and across all levels of education (Wing, 2012). Developing CT features prominently in both English and Scottish computing and technology education policy (DfE, 2013; Education Scotland, 2016). The need for accessible and engaging educational tools for CT has recently been acknowledged as significant and a wealth of educational material is being developed (Bocconi et al, 2016). However, these new materials are lacking efficacy-testing as the measurement of CT as an educational outcome is still in its infancy (Denning and Tedre, 2019; de Araujo et al, 2016).

1.2 Glitchspace

The first-person, puzzle-platformer game Glitchspace (Space Budgie, 2016) was the result of an academia-industry collaboration with the aim to encourage engagement with STEM fields. In the game, the player can use a visual programming interface to manipulate objects in the virtual world to solve puzzles and escape the cybermaze. The game was critically successful and was awarded a British Academy Scotland Award (BAFTA Scotland, 2016) for its innovative gameplay. A study on Glitchspace's UX design revealed that players found the game motivating and enjoyed its game mechanics (Donald & MacLeod, 2017). However, while the game was shown to be engaging and motivating, its educational potential in relation to CT ability has not been explored, as no efficacy-testing or intervention studies were carried out. This presents an opportunity to study the learning potential for CT ability in a game that has already been shown to be successful at engaging players.

1.3 Linking Gameplay Metrics to Computational Thinking

1.3.1 Games and Computational Thinking

There is a substantial history of using play and games to teach computer science concepts and programming going all the way back to at least the LOGO language, which sought to not only engage young learners, but to present a new teaching paradigm based on experiential learning principles (Papert, 1980). More recently, CS Unplugged has been gaining in popularity and influencings the design of the K-12 curriculum recommendations from the Association for Computing Machinery and code.org (Denning and Tedre, 2019). However, much like any other CT educational materials, there is still little robust evidence of the efficacy of these game approaches.

1.3.2 Game Analytics and Psychometric Design

Evidence-centred design (ECD) is one approach to measuring player competencies that has been gaining traction in the applied games literature (de Klerk, Veldkamp and Eggen, 2015). In a typical scenario of using ECD in a game the player performs actions prompted by the virtual world, where some of those actions feed into an evidence model in order to make inferences about the state of the learner's competencies. Statistically this can be implemented as a Bayesian network that continuously updates its inference on the student's knowledge (competency) as new data (gameplay evidence) is recorded while they play.

One issue with implementing ECD in complex games with lots of degrees of freedom is the challenge of defining the evidence model: how do we know which actions constitute evidence of the desired learning and how do we statistically link them to the student's competencies? This is usually a laborious process that often involves coding of behaviours by content experts, psychometricians and others (Georgiadis and Westera, 2019). For an example in CT game-based assessment see Rowe et al (2018) and for problem-solving Shute et al (2016).

It has been suggested that exploratory data analysis can identify patterns of gameplay behaviour for potential evidence of learning (DiCerbo et al, 2015). This could even be automatized to a degree with the use of machine learning methods as in Georgiadis and Westera (2019). These data mining approaches can simplify the process of finding out the patterns of behaviour that are learned while playing. Our project will add to these attempts the validation of the discovered links between behavioural patterns of gameplay and the desired CT learning outcomes using controlled experiments.

2. Method

We outline the necessary steps for a systematic study of the relationship between gameplay behaviour and CT ability. Building on these and on experimental validation we will develop robust methodologies for the measurement of CT from gameplay data and aid design decisions for learning enhancement. Summary of our main method can be seen in Figure 1 below.

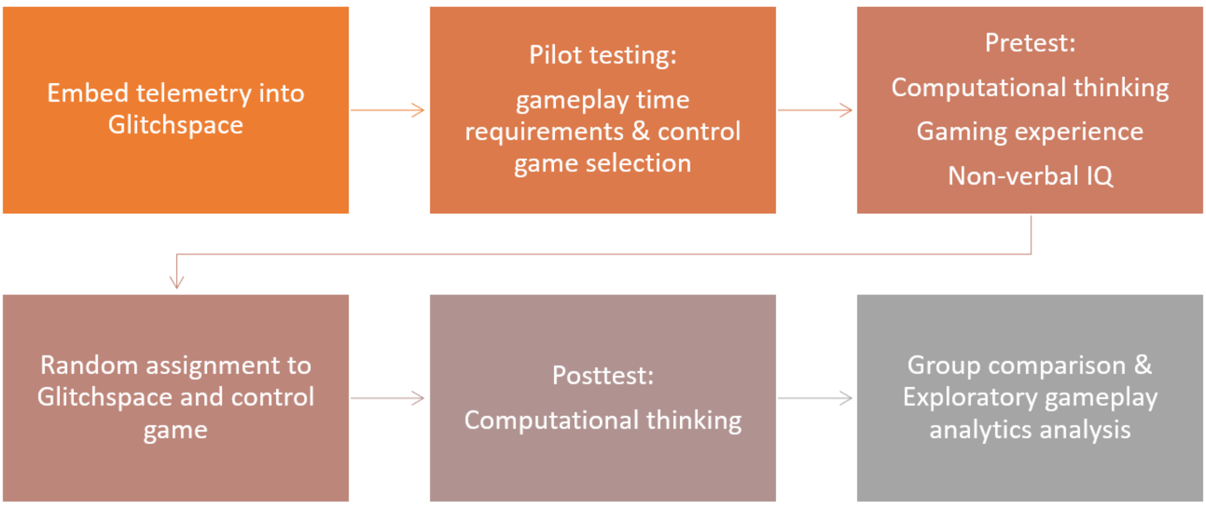

Figure 1: Proposed research methodology.

2.1 Embedding Telemetry and Pilot Testing

Glitchspace must be equipped with the necessary telemetry to measure player performance in meaningful ways suited to learning analytics. Basic game ability metrics, such as completion times and number of failed attempts of various sub-tasks will be measured, as will comprehensive log files of player actions in the game – this will provide us with a rich dataset to explore for emerging patterns of learning. Pilot studies with players can reveal how much time is typically needed to become proficient at the game, as well as allow for preliminary exploratory analyses to inform analytics development.

2.2 Initial Intervention Study

Participants will be recruited from 1st year undergraduate students and randomly assigned to either playing Glitchspace or a control game. It is preferable for the control to be a game rather than a non-game as there are fewer differences in administration and provides better experimental control (Mayer, 2014). In addition, based on pilot studies we will determine a control game that is matched to Glitchspace in terms of average gameplay time. A narrative-based game revolving around non-technical matters, rather than a problem-solving game assures the games are different enough on the relevant cognitive and gameplay aspects.

We will employ a pretest-posttest design to measure CT learning in both games using validated techniques, as described in Román-González et al (2019). To account for individual differences we will also administer tests of cognitive ability (using non-verbal IQ-tests) and gaming experience (measured by a questionnaire). It is plausible for example that students with different levels of gaming experience and/or non-verbal IQ benefit more from the game than other groups and these measurements allow us to control for that.

CT ability improvement will be compared between the Glitchspace and the control group to establish the learning gain in CT. Furthermore, in addition to the basic game ability metrics, patterns of behaviour identified in the exploratory analysis will be compared with CT measurements through correlational tests. This will allow us to establish whether there is a link between CT and gameplay metrics.

2.3 Learning Enhancement

Provided the first intervention study establishes a firm learning baseline and validates the robustness of the novel gameplay measurements, the project could proceed to learning enhancement. Educational game design changes and additions will be proposed based on careful analysis of the gathered data and a survey of the CT education literature for the cognitive foundations of CT. These proposed enhancements will be implemented, and a series of experiments will evaluate their efficacy. These experiments will be informative not only in terms of how to improve the educational design of the game, but also in terms of clarifying the relationship between CT and underlying cognitive processes.

3. Conclusion

We have presented the foundations for a robust methodology combining exploratory data analysis of gameplay metrics as indicators for learning gains while controlling for individual differences. In particular, effects on computational thinking ability will be explored in the critically successful game Glitchspace as a promising case study of this methodology. Our findings will be of great interest to instructional designers seeking to use games for CT education, as well as applied game analysts seeking to model learning from gameplay behaviour.

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