

Title	Embracing the universal design for learning framework in digital game based learning - a set of game design principles
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Publication date	2018
Original Citation	CUNNINGHAM, L. and MURPHY, O., 2018, October. Embracing the Universal Design for Learning Framework in Digital Game Based Learning. In Transforming our World Through Design, Diversity and Education: Proceedings of Universal Design and Higher Education in Transformation Congress 2018 .Vol. 256. IOS Press. (11pp). DOI:10.3233/978-1-61499-923-2-409
Type of publication	Article (peer-reviewed)
Link to publisher's version	http://ebooks.iospress.nl/publication/50589 - 10.3233/978-1-61499-923-2-409
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Download date	2024-04-25 15:57:54
Item downloaded from	https://hdl.handle.net/10468/8447

Embracing the Universal Design for Learning Framework in Digital Game Based Learning

A Set of Game Design Principles

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Abstract. The Universal Design for Learning (UDL) framework emphasizes multiplicity of representation, expression and engagement to cater for the widest possible set of learning styles and abilities. Digital Game Based Learning (DGBL) can slot into a universally designed approach to education as one of several alternative ways of learning that will suit some learning preferences, such as those who prefer to learn in an active way. However, DGBL can itself encapsulate the principles of UDL if the game designer embraces UDL as a fundamental set of game design principles. This paper discusses, with examples, the ways in which a game designer can universally design a DGBL solution with respect to game mechanics, representation and personalization, with an emphasis on the use of gameplay data for formative and summative evaluation during the design, build and retrospective phases, as well as for adaptive learning and formative feedback during the delivery phase.

Keywords. Universal design for learning, game based learning, learning analytics

1. Introduction

Universal Design for Learning (UDL) is a framework for the design and delivery of mainstream education that caters for learners from the widest possible set of backgrounds and abilities. The UDL framework provides for a multiplicity of representation, expression and engagement, as set out by the Center for Applied Special Technology [1]. While often associated with making learning accessible to people with disabilities, the framework is for all learners.

Serious games are games which have education, in its various forms, as the primary goal instead of entertainment, though that does not mean that they should necessarily be solemn experiences lacking in entertainment [2,3,4]. Serious games have seen rapid growth for more than a decade in both academia and industry, in areas such as education, cultural heritage, well-being and health care, and they have huge potential in improving achievements in these areas and others [3,5].

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Under the umbrella of serious games is Digital Game Based Learning (DGBL), which is the use of video games to deliver learning outcomes in a way that engages learners ([6] provides a list of other sub-genres, such as edutainment and games for change). Several studies have shown that video games have the potential to enhance learner experiences and outcomes when compared with more traditional teaching approaches [3,7].

The aim of this paper is to outline a set of guidelines for the design of DGBL that adheres to the principles of the UDL framework. The guidelines have been devised from a combination of literature review and a study carried out using Virtual Reality (VR) as the medium for a DGBL solution that teaches the fundamentals of graph theory.

2. The Adaptive Model for DGBL

A model was devised as part of this research for the purpose of designing, building and delivering DGBL solutions that clearly map learning outcomes to a game, including the ability to record and visualize progression of learning for both the learner and educator.

The model is adaptive from several perspectives, including:

- iterative formative evaluation allows the designer to adapt the game to learners based on gameplay experiences;
- retrospective summative evaluation allows the designer to adapt the game for future cohorts;
- the delivery of learning can adapt in real-time to the learner based on a learner's interactions with the game;
- prompt formative feedback in-game allows learners to adapt their approach to challenges and exercises;
- visualizations of learning allow learners to adapt future learning.

Figure 1 shows some of the key steps and phases in the model. Central to the model is the use of learning analytics (LA). The major focus to date of LA has been virtual learning environments (VLEs), with a particular emphasis on key metrics, such as logins and engagement, for the purpose of identifying when to intervene with an individual learner or where a module or course has an issue across many learners [8]. However, LA when combined with DGBL also provides an opportunity to analyse the way in which learners learn and provide fine-grained visualizations of performance and learning progression.

[9] outlines how LA can be used to improve the design and delivery of DGBL. Behavioural and outcome data can be stored, analysed and visualized. For example, the revised Bloom's taxonomy [10] cognitive domain is a progression from basic remembering through to creating. A DGBL solution can be programmed to store data when observable events occur, such as when the learner demonstrates a particular level of comprehension (for example, by completing an in-game exercise). The progression of learning can then be visualized.

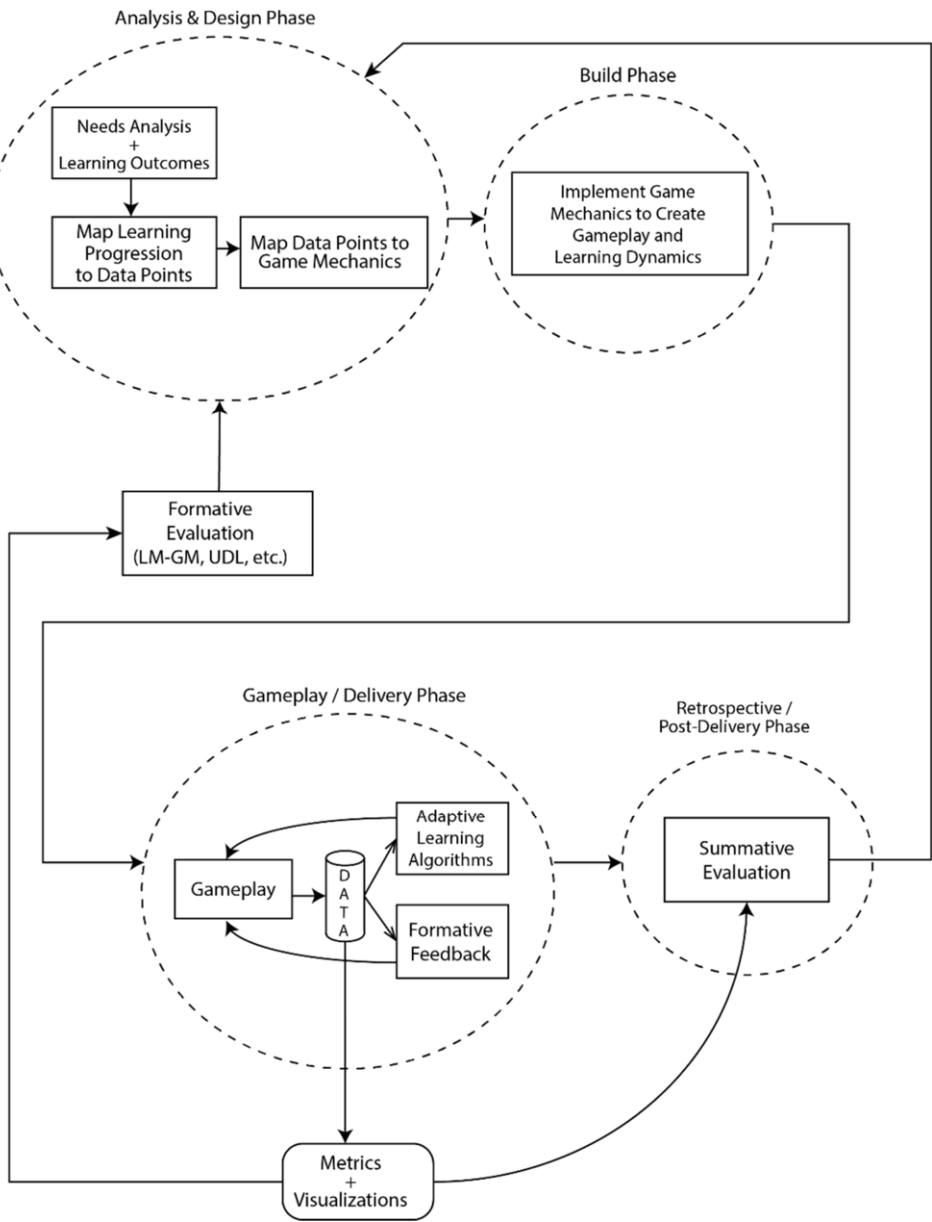


Figure 1. The Adaptive Model for DGBL.

Changes in state, such as moving from a lower level of understanding to a higher level of understanding, are identified and these become data points for storage. How those transitions occur will depend on game mechanics (GM) and how they are mapped to learning mechanics (LM) – the LM-GM model can be used to evaluate how well this has been done [11].

3. A Learning Analytics Platform for DGBL

Accompanying the model is a platform for DGBL with a centralised application programming interface (API) and dashboard. The platform allows learners view their learning progression and gauge progress relative to other learners. Educators can access data that allows them to identify how students are performing or where intervention might be required.

Some learner-focused features include:

- Badges
- Leaderboards
- Visualization of learning progression mapped to a taxonomy of learning
- Visualizations of exercise performance

Some educator-focused features include:

- Ability to map learning outcomes to labels, which are communicated by the game to the API to indicate a learning outcome has been met;
- Dashboard alerts that warn about students potentially in need of intervention;
- Ability to log an audit trail of all learner interactions for data analytics purposes.

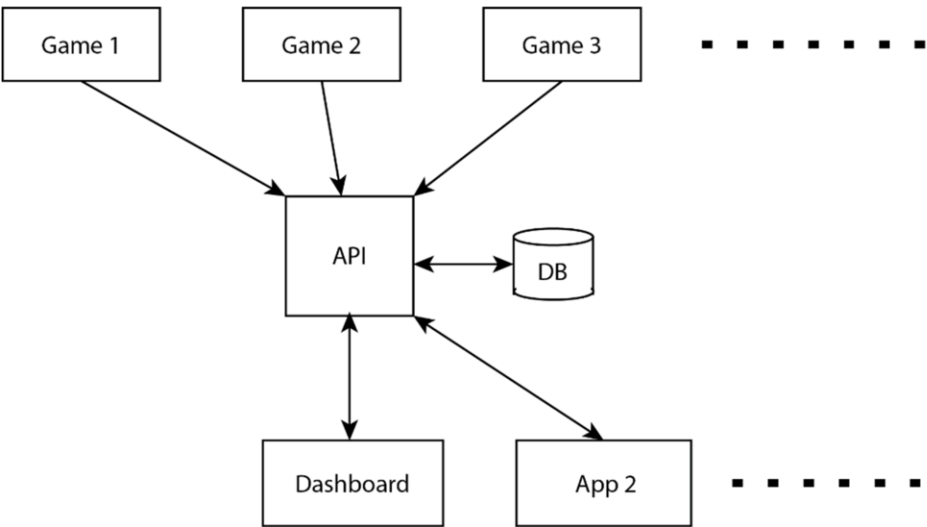


Figure 2. The DGBL Platform.

Figure 2 shows how this platform can cater for many games and applications that use the data. These applications could include a visualization dashboard or a utility for exporting data to a VLE. The use of an API and the decoupling of data storage from games and applications makes it a flexible and scalable platform.

4. The Universal Design for Learning Framework

The framework is presented as a three-by-three grid (Figure 3). Within the grid, as per version 2.2 of the UDL framework, are 31 numbered *checkpoints*, which are accompanied by examples. The columns organise the checkpoints under multiple means of *engagement* (the why of learning), *representation* (the what) and *action and expression* (the how).

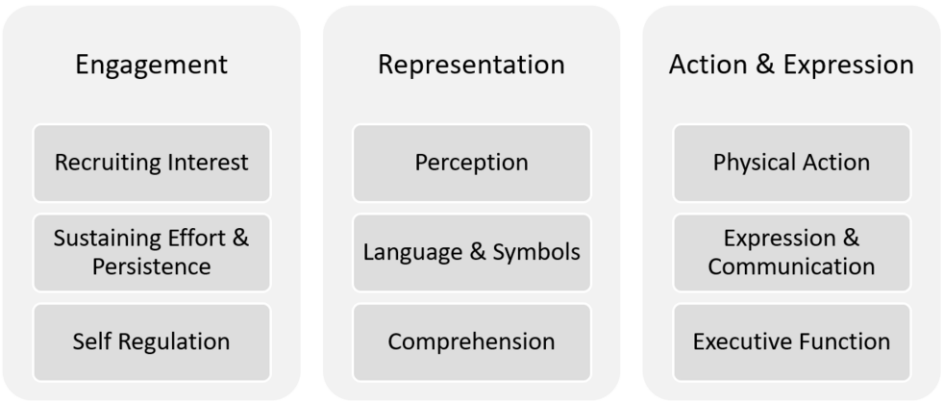


Figure 3. The UDL Framework.

As an example, the *Sustaining Effort & Persistence* cell of the grid is numbered 8 and contains four checkpoints. Checkpoint 8.1 – “Heighten salience of goals and objectives” – contains six examples of how to do so.

The framework can be used to inform the upfront design of a DGBL solution, but it can also be used as a checklist when performing formative evaluation to evaluate how universally designed the solution is.

5. The Adaptive Model for DGBL: A Case Study

To demonstrate the model in action, a subject was chosen: graph theory, which is a fundamental area of mathematics used widely in computer science. Figure 4 is a directed graph, which uses arrows to indicate directionality of relationships between vertices (the black circles).

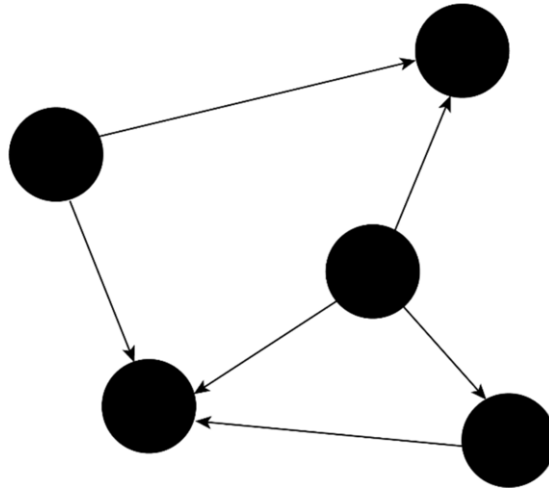


Figure 4. A directed graph.

The computer science curriculum in Cork Institute of Technology and text books were consulted during the needs analysis to determine learning outcomes for an introductory module on the fundamentals of graph theory. The learning outcomes were mapped to Biggs's SOLO taxonomy [12]. Before the learner could begin to complete graphs they first needed a *unistructural* comprehension – the learner was presented with examples of simple constructs such as vertices and edges. The next progression was to a *multistructural* level of comprehension, which is to connect vertices using edges. The next progression was to a *relational* level of understanding by learning how to connect vertices according to rules; during the initial tutorial level, the rule was simple: connect vertices of the same colour. Later progression involved more complex rules, such as connecting vertices containing words if they were synonyms of each other.

Each learning progression is a change of state that can be mapped to a data point for storage, allowing for visualization and analysis, but also for adaptive or personalized learning in real-time (for example, only presenting new content when prerequisites have been met).

6. An Overview of the Graph Game

The graph game was developed for the Oculus Rift VR platform. A hypothesis was that VR as a medium would suit certain learning preferences (particularly those who state a preference for visual or hands-on learning) and offer additional choice to students (alongside traditional approaches).

In the game, players have the ability to grab cubes (representing vertices) with their virtual hands and connect them together with lines (representing edges) (see Figure 5). The game begins with a tutorial level to guide the player through the game's core mechanics and the fundamental building blocks of graphs – vertices, edges and connecting them to create graphs according to set rules. Subsequent levels allow the player to play around with real-world examples (a social graph and a natural language processing graph). These are followed by more difficult graph exercises to complete.

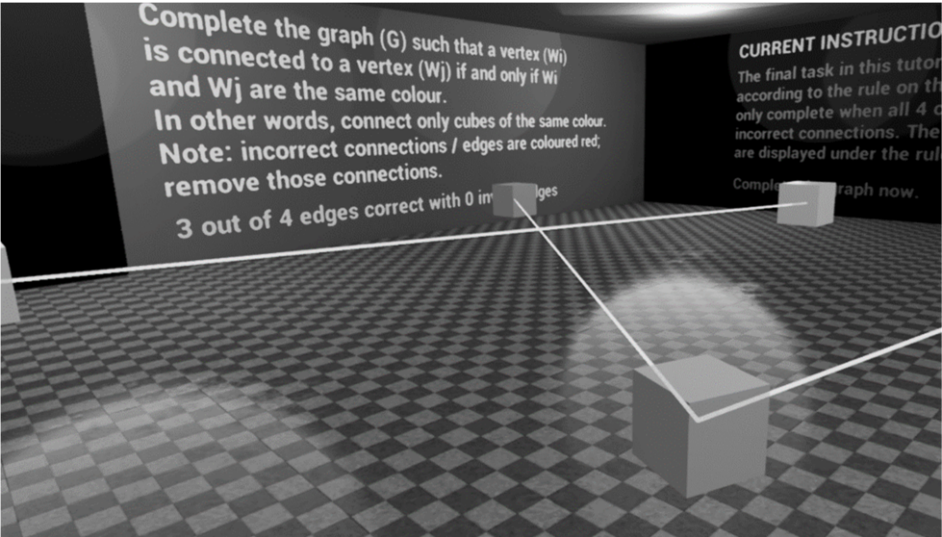


Figure 5. Connected vertices in the graph game along with instructions and rule text.

When a player completes a learning outcome, it is communicated to the API, which stores the data (along with timestamp) in a database. Other metrics are gathered, such as level of engagement examples (a combination of time spent viewing an example and interacting with it).

After the gameplay session, players can login to a dashboard to view visualizations. Figure 6 shows a visualization of a player’s learning progression.

Learning Outcome	Complexity	Completion
1..... Demonstrate an understanding of the fundamentals of graph theory	Relational <div><div></div></div>	67% <div><div></div></div>
1.1..... Understand what a vertex and node is	Unistructural <div><div></div></div>	✓
1.2..... Connect vertices with an edge	Multistructural <div><div></div></div>	✓
1.3..... Calculate the shortest path using an appropriate algorithm	Relational <div><div></div></div>	
2..... Complete graphs from sets of rules	Relational <div><div></div></div>	100% <div><div></div></div>
2.1..... Complete a graph according to a simple rule	Multistructural <div><div></div></div>	✓
2.2..... Complete a word graph according to a complex rule	Relational <div><div></div></div>	✓
3..... Apply graph theory fundamentals to real world problems	Extended Abstract <div><div></div></div>	50% <div><div></div></div>
3.1..... Manipulate example graphs representing the real world	Multistructural <div><div></div></div>	✓
3.2..... Construct a graph that represents a real world problem	Extended Abstract <div><div></div></div>	

Figure 6. Visualization of learning progression mapped to SOLO taxonomy.

7. Study Methodology

A mixed methods-based research protocol was devised for the study that included observation, think aloud and the administration of a questionnaire to the participants in the study (N=20).

The questionnaire was organised into sections that asked questions mapped to the following:

- A model for the evaluation of DGBL [13] that suggests measuring cognitive learning outcomes, motivational outcomes and efficiency outcomes;
- Progression of understanding mapped to Biggs's SOLO taxonomy [12];
- Formative feedback provided within the game and the dashboard;
- How captured gameplay data might be used;
- The UDL framework.

Participants were invited to express verbally whatever they were thinking as they played the game. Observational notes were taken while watching gameplay on a projector screen. Notes were taken on learner behaviour, such as difficulties with controls or strategies employed while solving challenges. When the study was complete, gameplay data was analysed.

8. Guidelines for Universally Designed DGBL

An attempt to map guidelines to each of the 31 checkpoints in the UDL framework could be unwieldy and could quickly become out-of-date as the UDL framework evolves. Instead, some general guidelines informed by the findings of the study are presented with the overarching guideline from a UDL perspective of using the framework as a checklist of questions to ask during the formative evaluation phase of an iterative DGBL model. Some of the guidelines have been mapped at a high level to the "multiple means" headings of the UDL framework.

8.1. Use an Iterative DGBL Model

As discussed previously, an iterative approach was taken to developing the graph game. Issues from a UDL perspective were discovered in each iteration of the game's prototype (there were three iterations for the purposes of the study). The cumulative effect of resolving the issues was a prototype that was more universally accessible and usable.

Select appropriate models to evaluate various aspects of DGBL in each iteration of the prototype. Three used while developing the graph game were the LM-GM model to evaluate the types of learning taking place, the UDL framework and its checkpoints (further discussed in the next section), and the model proposed by [13] to measure cognitive, motivational and efficiency outcomes. Other mechanisms could be considered, such as the SUS questionnaire [14] to measure usability or other custom-developed questionnaires with more specific questions about game mechanics and so on.

8.2. Use the UDL Framework as a Checklist

The UDL framework allows the designer drill down to examples of what constitute universal ways of delivering learning. The 31 checkpoints can be used as a checklist. When reviewing each iteration of a prototype, the designer can ask these 31 questions of the prototype. For small DGBL solutions, not all questions might be relevant, so a not applicable response could be given to those questions after some consideration. However, DGBL solutions are usually embedded in a larger context – there may be teachers or tutors supporting a group of learners, so while a DGBL solution might not contain an embedded mechanic for reflection, there may be a related follow-up such as a reflective essay or a group discussion.

8.3. Consider Gathering Data for Learning Analytics and Adaptive Learning

This is perhaps the central tenet of the Adaptive Model for DGBL. Learning analytics is characterized by pre-planning, for example mapping learning outcomes to data or storing values for the purpose of calculating key metrics; the purpose of storing these data points is understood in advance as are the stakeholders interested in the data. A complementary area of research is educational data mining (EDM) where raw data is mined for valuable insights ([15] provides an overview and comparison of LA and EDM). EDM is associated more with use of machine learning and data mining, and the value of the data might only become apparent after the DGBL solution has been built and delivered. There is an argument, therefore, for erring on the side of caution and storing as much data as possible (effectively an audit trail of all learner interactions) since the use of the data might become known later. In addition, when using machine learning, such as for adaptive learning purposes, it must be trained using prior student interactions with the DGBL solution.

8.4. Do not Over-specify a Game

Relevant to: Engagement (from the perspective that over-specifying a game reduces choice for those without the required specification)

There is a computational cost to every polygon in every 3D model in a 3D game. The higher the fidelity of the graphics in a game, the higher the hardware requirement and the greater the cost of purchasing the required equipment. If a game is being made available outside the bounds of the teaching institution developing it, such as availability via a web browser or as a digital download, then try to build the game for the lowest possible hardware specification. The graph game uses simple shapes, such as cubes, which are inexpensive for a GPU to render; this would be relevant if a non-VR version was made available. Learner experience and outcomes in the graph game were high despite the simplicity of the graphics. Not over-specifying a game will improve access not just for lower socioeconomic groups, but for anyone who has no need of a high-end gaming PC.

8.5. Control Schemes and Controllers

Relevant to: Action and Expression

There are several approaches to a game's controls from a UDL perspective. The first is to employ widely-used controllers, such as joysticks, gamepads, or mouse and

keyboard, and then design the game's control scheme to be as accessible as possible. To improve accessibility, a minimal approach to the control scheme should be taken. During the research study, Oculus Rift dual touch controllers were used. The left and right-hand controllers have six buttons each. After an analysis of observations from the first study, it was decided to remove one of the buttons from the control scheme – searching for several buttons with a headset on proved challenging for some.

The control scheme was mirrored on the left and right-hand controllers – more accessible for left-handed people or those without the use of a left or right hand. The advantage of using both controllers in the game is that the player sees two hands (if both are available), improving the sense of immersion and proprioception.

The second approach is to support specialised controllers that have been designed for players with disabilities. This includes the disability-friendly XBOX controller, which allows the player to use feet, elbows or hands, even where fingers might be missing [16]. Another example is the “camera mouse”, which has been tested on people with cerebral palsy and traumatic brain injury [17]. While these controllers allow existing control schemes to be used, the principle of minimal control schemes still applies.

VR introduces a third approach. A VR headset can also be a controller. Internal and external sensors allow head position to be tracked. In the graph game, a dot is superimposed on the player's view. As the player's head moves, the player can use the dot to aim at objects. Through careful design, it is possible to implement a control scheme based only on this gaze mechanic in most DGBL solutions.

The final approaches discussed here are more experimental: eye tracking and brain-computer interfaces (BCI). Both approaches could be used for cases where movement is extremely limited or unstable. [18] uses eye tracking to improve immersion in a game. [19] discusses the use of both eye tracking and BCI for game control.

8.6. Make Design Decisions Early That Affect Accessibility

Relevant to: Representation

Spend enough time during the analysis and design phase thinking about accessibility before a line of code is written. A classic example is internationalization: is it intended for the game to be played by international students? A designer might not anticipate the need for it at the time, but allowing for internationalization can be an inexpensive up-front decision. For example, in the popular game engine Unreal Engine 4, this is as simple as using Text variables instead of String variables for any displayed text. The former generates an associated hash value (a lookup key) that can be associated with multiple translations of the text – a simple change of a setting in a game can switch between languages. The latter type of variable cannot be changed without manually editing the string value and recompiling. If a project is months into development and with hundreds or thousands of string variables, changing to an internationalized version of the game becomes a very expensive operation.

8.7. Give Prompt Feedback

Relevant to: Engagement

A significant advantage that DGBL has over traditional learning is the ability to provide prompt feedback, a principle of good educational practice according to [20]. Videogames can algorithmically check student progress and provide feedback as soon as a player performs a task. An example from the graph game is the use of colour to

distinguish correct connections from incorrect connections. When an incorrect connection is made between vertices, the line is red. When it is correct it is green. An alternative to account for colour blindness would be to have lines flash when incorrect.

While completing exercises, the player is told how many correct connections have been made (versus the total required) and how many incorrect connections have been made. Paper-based versions of the exercise would either need to be corrected by an instructor or the learner might go to a solution at the back of a textbook. Neither approach provides immediate formative feedback during the exercise.

Another type of feedback is comparative and this can be achieved with leaderboards or by allowing learners to view the badges of others.

8.8. Let Players Know How They Are Doing and Where They Are Going

Relevant to: Engagement

Figure 6 is a visualization that summarizes how a learner has progressed through the graph game. Signposting goals and objectives clearly helps to “sustain effort [and] persistence” as per the UDL framework. Other visualizations, such as learner performance when completing challenges, can help learners in their drive to improve and assist with self-regulation.

9. Conclusion

The UDL framework can play a key part in an iterative approach to the development of DGBL solutions. The set of guidelines presented are not meant to be exhaustive, but when followed can address some of the checkpoints contained in the UDL framework. The Adaptive Model for DGBL incorporates the UDL framework as part of its formative evaluation step as a checklist of questions to evaluate how universally designed the solution is. When the answer to a checkpoint question is not yes, the designer must decide if the checkpoint is not applicable (such as when the question is addressed by a learning mechanic outside the game) or if it needs to be addressed in the next iteration of the prototype.

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