

A Framework to Help Analyze if Creating a Game to Teach a Learning Objective is Worth the Work

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Abstract—Video games are a popular technology adopted by educators to help teach ideas. The benefits are due to pedagogically beneficial characteristics of such games including their ability to adapt to the learner, allow failure, and entertain and engage players. However, designing a video game is a significant effort that takes time and may not even teach the desired learning objective(s). In this work, we provide a framework that can be used by educators to help determine if the effort needed to create a video game is worth it for a given learning objective(s). Our framework blends four pedagogical ideas so that educators can consider if their game is worth the design effort; these pedagogical tools/theories include: (1) Bloom’s taxonomy; (2) the Substitution Augmentation Modification Redefinition (SAMR) Model; (3) Wiggins & McTighe course design approach and filter for learning objectives; (4) what we call, pedagogical logistics. With this framework, we analyze two games we have created, and we determine if the games we created were actually worth the effort. The overall goal is to create a framework and show how it can be used to help other researchers determine if their video game idea is worth creating.

I. INTRODUCTION

Most new technologies that emerge in modern society are examined as potential additions to education to improve the teaching and learning process. Video games are no exception, and since their conception in the seventies and eighties, they have been examined as possible additions to education. In particular, video game characteristics such as adapting to learners current ability, allowing for safe failure, and engagement are all qualities that are very attractive if they could be leveraged for learning [1]. For this reason, a number of attempts have been made to integrate games and learning.

Video games, however, are massive developmental undertakings. One person can replicate and program a game from the 1980’s in about a day, but to actually create a new game including designing, prototyping, implementing, and testing can take many human resourced months or years for even simple games. Additionally, all of the desired qualities of video games that we would like are not a guarantee, and instead, these qualities need to be carefully designed and tested. Therefore, as much as we would like to simply create games that help students learn ideas, there is a lot to consider.

In this work, we provide a framework which will help determine if the high effort needed to create a learning-based

video game is worth the effort. The goal of this framework is to link a number of pedagogical theories and ideas to an imagined artifact (a video game) to help educators evaluate their idea comparing the pedagogical benefit to the student. In particular, our framework uses ideas from three aspects of pedagogical research and best practices including:

- 1) Bloom’s taxonomy of educational objectives [2]
- 2) The SAMR model for technology and education [3]
- 3) Course design with a backwards approach described in “Understanding by Design” [4]

A fourth aspect to our model, we call pedagogical logistics, which examines how a learning objective is, currently, taught and how it impacts the classroom versus how those activities would change if a video game was created to help teach and learn the respective objective.

Once we describe our model, we use the framework to look at two games we have created, and we show how the framework would help us determine if our time spent was worth the effort independent of the evaluation of the effectiveness of those games. Hopefully, this will allow other researchers and teachers to start analyzing their educational video game ideas before making a major design effort that is not justified by the learning impact. In short, we propose a much needed framework for preliminary examination of efficacy before substantial resources are committed to the production of a new game.

The remainder of this paper is organized as follows: Section II describes what the community has learned in designing video games for the classroom and provides a basis of what learning is. Section III describes the framework as related to creating a video game for teaching a learning objective. Section IV provides two examples of applying this framework to existing games that we have created. Finally, section V concludes the paper and provides a brief discussion of future work.

II. BACKGROUND - GAMES AND LEARNING

Games, which includes video games, are activities defined as [5] (one of many definitions):

- 1) A game has a set of rules

- 2) A game provides feedback to the players
- 3) A game is voluntary

Higher education includes the same set of defining features. And yet, the striking difference between games and education is that most people become highly engaged with some games, but not so much with much of their education. Video games can also engage a large portion of the population, and people have speculated that this is the case because the game design (through the machines control) can present a user with a challenge that is just above their skill level evoking a flow state. The flow state is “In such a state a person feels fully alive and in control, because he or she can direct the flow of reciprocal information that unites person and environment in an interactive system” [6].

A third quality of games is the idea of a safe domain to fail in to the point where it is expected [7]. In education, it is very hard to fail, and in many cases within the education system, failure is a disaster, especially in the high stakes assessment that we typically employ [8]. Video games present failure as a low stakes assessment or a feedback point that shows you have learned or not learned a solution or skill to complete the task - yet. Note, not many people ride a bike, solve a differential equation, or read a sentence perfectly the first time they make an attempt at these skills and problems, but high stakes evaluation at an expected pace that is not tailored to the individual is a common approach in our educational systems.

Because of the qualities and relationship between games and learning, many people have researched games as learning environments to improve student learning [9]. Below, we list 4 recent attempts by researchers in technical subjects just to show the range of ideas of using games for learning:

- Sol and Stephens created a game to teach statistics [10]
- Navarro *et. al.* built a game to help students learn radio communication [11]
- Lyon *et. al.* created, Little Newton, to teach physics [12]
- Cheng *et. al.* built an educational game for learning immunology [13]
- Grace *et. al.* (the authors) built a game to teach learning digital hardware design [14]

This is a very small sample of games that focus on helping students learn with video games.

The field of games used for other purposes than just entertainment continues to grow, and this paper can not provide a full introduction to this large subject. We direct the interested reader to Susi *et. al.* [15] as a place to start learning more about this field, and for some of the more directed questions of games and entertainment, we suggest reading Mitchell and Savill-Smith’s work [16]. Also there exists some more modern surveys of the impact on learning with video games [17], [18].

Many researchers pursue an idea for a learning game with vigor, imagining that the only way to evaluate its efficacy is with a prototype. Few of us have been trained to ask about the games potential prior, particularly, because we have systems

(such as grants) that encourage people to commit early to a final product and deliver. The result is a system that rewards and incentivizes people to demonstrate efficacy even if it’s marginal. Asking the questions proposed in this work affords for effective and critical dialogue before designs are solidified.

Additionally, players are developing their own play literacy. Where once any game was an improvement from a text book, players are becoming increasingly critical of game experiences as the games they engage with have become more complex, more distinct, and more rich. Players are playing more and there are more games to play than ever before thanks to mobile play [19]. As a result, players have a more mature expectations of games. This is no surprise as this is the pattern demonstrated in other educational media, whether it’s the history of film, animation or slide-shows the audience’s expectations evolve and grow as the mainstream entertainment medium matures.

There is developing evidence that it is not enough to have the elements of a game, it must actually feel like a game. There’s a growing concern about making sure that games, actually, demonstrate their efficacy. A recent study outlines understanding efficacy in games and measuring impact [20], which is fundamental in determining how we can better integrate games with education.

A. Learning Objectives and Reverse Design

Learning as we define it in this work is based on a number of sources ([21], [22]): “Learning is the stabilization of neural networks based on a desired response”. The importance of this definition is that we can relate the idea of learning things to the necessity of trying and doing things, since if the neurons are not firing (by thinking and doing) then the neural network is not wiring (Donald Hebb in 1949 stated, “neurons that fire together wire together”).

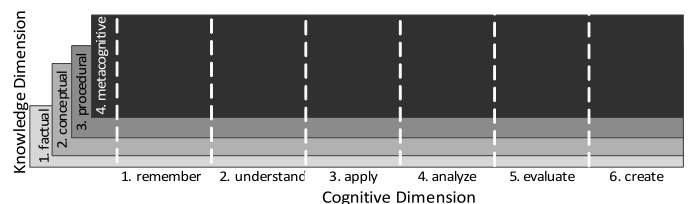


Fig. 1. The two dimensions of Bloom’s taxonomy [23]

A *learning objective* is a goal for a student such that they will be able to cognitively perform the objective once they have learned it. Typically, a learning objective is described by a cognitive process taken from the Bloom’s Taxonomy [2] and apply that to some content as related to the field of study. Bloom’s taxonomy provides a hierarchy of cognitive processes as defined from “lower-order thinking skills”, such as recall and classify, to “higher-order thinking skills” such as create or plan. The higher order thinking skills tend to be what society wants of workers, but these higher-order skills are much more challenging to develop and take significantly more time than the lower-order thinking skills to teach and learn. Figure 1 shows two dimensions of the Bloom’s taxonomy in terms of a cognitive and knowledge dimension [23].

A university level course in a particular subject matter will include a number of *learning objectives*. Wiggins and McTighe's book "Understanding by Design" [4] examines curriculum and course design by using *learning objectives* as a starting point, and then designing a course/curriculum in reverse from these starting goals. This approach is not always taken by university professors who, normally, lay out the material to teach first without a clear goal for student outcomes.

In this work, we lay out our framework by taking both games and learning and mapping the end artifact, the video game, into some of these theories and ideas with the hope of pre-determining if the significant design effort is worth the potential result. Note that there are many other publications about games and learning that we have not cited in this brief discussion (for example [24] and [25]).

III. FRAMEWORK FOR PRE-ANALYZING A GAME FOR LEARNING

As described earlier, our framework takes theories and ideas from the following:

- 1) Bloom's taxonomy of educational objectives [2]
- 2) Course design with a backwards approach described in "Understanding by Design" [4]
- 3) The SAMR model for technology and education [3]

The fourth aspect of our framework, pedagogical logistics, looks at the details of learning activities and how they are implemented in the respective class compared to how video game would be included in the same class. We will present our framework in pieces where each piece is described in a subsection. As we describe this framework we will also use a sample idea of a game for a class in "introduction to algorithms and programming".

A. Video Game Idea

When using this framework it is likely you have an idea for a video game that you would like to create or have to help teach something in your class. Your motivation is that a video game will provide students with a fun activity that engages them, allows them to fail, and is at a level which challenges them. All of these motivations may not be true, but you should have some reason why a video game might be better than the current methods. In our framework, you do not need an implementation of the game, but you should be able to imagine your game and how it roughly works. Key questions that you should be able to answer at this stage are:

- What does a player/learner do in the game?
- What idea or concept is the game meant to help teach students with?
- How do you learn to play the game (for example, what buttons do you need to know to perform an action in the game)?
- How long does the game take to play?
- On what platform(s) will the game be played (student's computer, mobile phone, universities' lab)?

These questions are high-level ideas about the video game. The importance of the questions is that they provide you with a simple model of what your game is in the environment you are imagining it to be used.

Our game for introductory programming is a simple game that teaches programming constructs by including a set of programming statements that the player has to order to produce a desired result. A player in this game starts with 5 to 20 programming statements and needs to order these statements before a print statement so that when run the print statement outputs and matches a predetermined result. This game might help students learn basic programming structures and how they can be ordered to do calculations. To play the game, players need to learn how to use their finger by dragging to reorder the statements, and how to press a button that simulates the result of their ordering of program statements (this might have a stepping function so students can watch the program simulation). A typical problem or level will have 5 to 20 statements to be ordered and will take around 5 to 10 minutes to solve. This game is intended to be run on a mobile device.

B. Learning Objective(s)

With your video game idea, you have answered what concept is the game meant to teach. This is the result or outcome of the activity, and we need to refine this objective as the starting point in this framework. Arguably, you should be creating a game that helps teach an existing learning objective in a course, but regardless, in designing the game you need to define a learning objective(s) as related to the game.

The learning objective needs to be defined in a sentence where a verb is taken from Bloom's taxonomy [2] and the object of the sentence describes some knowledge or skill. For example, our sample game might have the following learning objective, "A student should be able to *construct* a program that will then generate a desired output with a proper sequence of program statements". This objective is *apply* in Bloom's taxonomy cognitive process dimension [2] and is *procedural* in the knowledge dimension [23]. From the taxonomy this learning objective would be considered a "middle order thinking skill".

To further determine how important the learning objective is, we suggest using Wiggins and McTighe's filter for learning objectives [4]:

- 1) worth being familiar with
- 2) important to know and do
- 3) enduring understanding

where the importance of the learning objective is more important to the student's future as the number increases above. This filter allows a teacher to consider their learning objective and qualify how important it is. The reason this step is useful is that just because an objective ranks as a "low order thinking skill" if it is an enduring concept for that student in the respective field, then it is important to emphasize and should be achieved by the student.

In our example game, our learning objective might be considered an "important to know and do" since if you can not order existing programs to generate a result it will be

even harder to create a program from nothing but knowledge of programming syntax and semantics.

C. SAMR model view of the technology

The SAMR model [3] stands for Substitution, Augmentation, Modification, and Redefinition, and the model is used to classify technology applied to education in terms of its' impact on teaching and learning. Each of the classifications of a technology in relation to what currently is done in class are briefly defined as:

- Substitution - The technology replaces an existing technology, but a learning activity is done the same way.
- Augmentation - The technology offers a more efficient way to achieve a learning activity.
- Modification - The technology allows for a learning activity to be done in ways not possible before.
- Redefinition - The technology allows for a learning activity to be created resulting in more and deeper learning activities.

The benefit of this classification is it helps you look at your potential game in terms of how does it compare to the existing way you create activities for your students. If your game fits in the "substitution" classification, then we recommend you find other strong motivations as to why you are making this game. Also, many games will be classified as "modification" since they present the problem in a new way, while "redefinition" classified games will be rare and harder to build since these types of games will tend to need to have characteristics such as collaboration or open endedness, which are challenging to design and engineer compared to a single-person puzzle like game or simulation.

Our example game is an example of "augmentation" since it is possible to already do this programming task on paper, but is more efficient on a machine. The game format is much more efficient compared to performing this task on paper; however, if you already did this exercise with a compiler and debugger on a computer then the video game might be classified as a "substitution" of the existing technology and a strong motivation of why we are creating the game should be considered.

D. Pedagogical Logistics

The last aspect of our framework for determining the benefit of creating a video game is examining the pedagogical logistics. We suggest that this can be done by comparing the existing activities used to teach the learning objective as compared to the planned video game. The following questions should be compared:

- Is this done in class and how much time does it take?
- Is this done outside class and how much time might it typically take?
- Are there additional technology needs?
- How will the learning objective be assessed?

IV. USING THIS FRAMEWORK TO EVALUATE GAMES

With our framework of ideas and theories, we will now show how to collect all this information, and we provide two analysis of games we have created to evaluate if they would have been good games to create for the intended learning objective. Note, that our two example games already exist, and we are performing this analysis in a different fashion than the tool is intended, but our hope is to provide examples of how to use the framework.

We propose the following table I to collect the information about your game idea as described in the previous sections. This table summarizes all the ideas as related to the video game and the associated learning outcome.

A. Game 1 - verilogTown

The first game we will analyze is called, verilogTown [14]. This game was created to help students in learning to develop hardware via a Hardware Design language - Verilog. The video game has players write control code for all the traffic lights in a cityscape in Verilog such that when the town is simulated and cars start trying to get to a predetermined destination there are no crashes and all cars are moved through the city in the shortest amount of time. Our major motivation was that students only use Verilog to create their labs and don't spend significant time playing with the language, and therefore, our hope was that a game might have them play with language longer than they typically would.

Table II shows the analysis of verilogTown. From a learning objective, Verilog design is an important concept to try and teach better. It is a high-order thinking skill and it is an enduring concept. From a pedagogical logistic perspective, the video game only changes the activities in the existing course by changing 2 hours of lab time. This is a small portion of the time spent teaching and learning Verilog design. Finally, the game is an *Augmentation* of an existing activity that is motivated with the hope that students will play the game longer than just creating a Verilog design for the lab and moving on. The reason for this is students already use computers to compile and test their Verilog, and the difference with the verilogTown is that the application of the Verilog design is shifted from a prototyping board [26] to a game and simulation environment.

With this analysis, we would probably not justify creating a video game for the learner impact. In hindsight, it took around 1.5 person years to create the game in its current state, and the game is only used for two hours when learning the course. We created this game for another reason other than the course; we wanted to prove that Verilog could be a language of design included in a video game. However, this game is not justifiable for the learning objective based on this framework compared to the high design costs.

B. Game 2 - Culture Code

Table III shows our analysis of Culture Code. In this case, the learning objective is not as significant as the previous game, but is still a higher-order thinking skill. In this case, the game is used as a simulation of what it is like to be in a culture where you don't know the rules of the game giving some people advantages just by the social construction of the rules, but

TABLE I. TABLE TO MAP RESULTS OF THE GAME IDEA

Game idea:		
Learning objective(s):		
Bloom's Taxonomy		
Cognitive Dimension:		
Knowledge Dimension:		
Wiggins & McTighe Filter: 1: Aware of—2: Know—3: Enduring		
	Original Activity	Video Game
SAMR classification	NA	Substitution—Augmentation—Modification—Redefinition
How much in class time?		
How much out of class time?		
Additional tech needed?		
Learning objective assessment?		
Other Motivation		

TABLE II. VERILOGTOWN EVALUATED IN OUR FRAMEWORK

Game idea:	A city simulation of cars traveling through a city. Players write the Verilog which controls the traffic lights. The goal is to get all cars through the city safely and as quick as possible.	
Learning objective(s):	A student should be able to <i>design</i> a system with inputs and outputs of a digital circuit as specified in Verilog	
Bloom's Taxonomy		
Cognitive Dimension:	7: create	
Knowledge Dimension:	3: procedural	
Wiggins & McTighe Filter: 1: Aware of—2: Know—3: <u>Enduring</u>		
	Original Activity	Video Game
SAMR classification	NA	Substitution— <u>Augmentation</u> —Modification—Redefinition
How much in class time?	10 - hours	10 hours where 2 - hours dedicated to verilogTown
How much out of class time?	5-20 hours	5-20 hours
Additional tech needed?	No	No
Learning objective assessment?	Completion of lab and exam question	Completion of lab and exam question
Other Motivation	NA	Hopefully, students will play longer than typical lab design time and will tend towards 20 hours of out of class time

there are no explicit explanation of the rules. This game is also a Modification of technology since there is a way to do this in class with a game called Barnge [27], but this takes significantly more time and does not handle as many players as the game version.

The pedagogical logistic impact for the game is small, but in this case, the experience that students get is very real and not comparable to just talking about the ideas of how it feels to be in an unknown culture. In addition, this game was built so that rules could be changed easily allowing the game to be used in other settings to impart cultural experiences and for researchers to implement some of their experiments. Therefore, because the video game allows a much deeper experience to help teach an enduring concept we would justify the effort to create the game. This game took around 0.5 person years to create.

V. DISCUSSION AND CONCLUSION

In this work, our goal was to connect learning theories and ideas to help decide if the creation of a video game to help students learn is worth the effort. The key ideas we leverage starts with Wiggins and McTighe's course design where you start from a learning objective and design in reverse. Next, we provided how to frame the learning objective on how important it is with Bloom's taxonomy and Wiggins and McTighe's filter. Once the learning objective is defined we then leverage the SAMR model to classify how the video game (as a technology) compares to existing activities used to teach the learning objective. Finally, our framework asks some pedagogical logistic questions that helps teachers compare their video game idea to what they already do. We applied this framework to two games that we created in the past and showed how our analysis would have given us a better picture of why or why not to spend a significant amount of design

TABLE III. CULTURE CODE EVALUATED IN OUR FRAMEWORK

Game idea:	This is a multi-player game in which players are put in teams and a team tries to eat as much food for their team in an allotted time. The teams, however, can see different things and some teams have better abilities compared to other teams.	
Learning objective(s):	A student should be able to <i>judge</i> how hidden cultural rules impact foreigners to a culture making what appears to be fair a challenging environment.	
Bloom's Taxonomy		
Cognitive Dimension:	6:analyze	
Knowledge Dimension:	2:conceptual	
Wiggins & McTighe Filter:	1:Aware of—2:Know—3: <u>Enduring</u>	
	Original Activity	Video Game
SAMR classification	NA	Substitution—Augmentation— <u>Modification</u> —Redefinition
How much in class time?	2 - hour lecture	2 - hours including playing game with reflection
How much out of class time?	0 hours	0 hours
Additional tech needed?	No	Yes - in class laptops
Learning objective assessment?	writing assignment	writing assignment
Other Motivation	NA	Program allows flexible environment to be created with varying rules to test social theories

time.

The question “should I make this game” does go beyond our framework in terms of designing a video game. In particular, we need to answer the scientific question of can games be used to teach ideas as good as or better than current methods due to characteristics such as safe failure and engagement? Our analysis, however, suggests that for many learning objectives that tend to target very specific skills, researchers and educators should spend more upfront time evaluating why a video game would be better than what already exists. Many video game artifacts that are both being funded by National research agencies and created for the academy are one off game implementations that may improve learning for a particular learning objective, but these games are not adopted at a scale that justifies the effort.

Essential to the continued success of games for learning is their ability to provide scalable, sustainable, and demonstrable impact. As the practice of such game design matures and as the criteria for efficacy analysis evolves we see an evident need to formalize the evaluate of game designs earlier in the process. This is particularly true as funding agencies, partners, and players become increasingly critical of the final game product. Where once it was enough to have implemented a small game that explicitly addressed a single, specific need it is clear that the increased commitment of resources and the increasingly competitive games domain requires more than small solutions for very specific impact.

Hopefully, the framework proposed is a good starting point to help all of us design video games that have a more significant benefit to the learners. Our own analysis of our games suggests that we should look to designing more open-ended simulation style games with collaboration, since these types of games allow for learners to create and solve their own problems. These types of games are difficult to create, but will,

likely, have a greater impact on games and learning.

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