To the Mun: *Kerbal Space Program* as Playful, Educational Experience

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Abstract. This paper is a case study illustrating how a digital game that conforms to what James Paul Gee terms good game design is one which encourages a state of cognitive flow engages players as a playful experience. This case study will review how good game design, combining flow and specific elements associated with the play outlined in the playful experience framework can lead to learning outcomes. The paper will look at specific designed elements of the game *Kerbal Space Program*, such as open and directed play modes and the community of player-participants and content creators as they relate to principles of learning and elements of pleasure framework to illustrate how good educational game design is pleasurable game design and by linking pleasure, play and learning.

Keywords: Play · Flow · PLEX framework · Educational games · Game studies

1 Introduction

Kerbal Space Program [16], or *KSP*, is a digital game where the player must create and maintain a civilian space program akin to the National Aeronautics and Space Administration. *KSP* gives players the chance to explore elements of astrophysics, physics, rocket science and aerospace engineering by constructing rockets, airplanes, and probes in a robust simulation of modern and near future space travel. *KSP* also has elements of an optimal experience allowing players to enter into a state of cognitive flow, and as a designed game experience, it simultaneously embraces multiple elements of the PLEX framework [3]. *KSP* is a perfect example of a game that serves an educational goal while simultaneously designed to be an engaging, playful experience. *KSP* was formally released in 2015 and has evolved from a sandbox rocket construction game where the goals are entirely self-directed to include a far more enriching, heavily designed, goal-based game where a series of soft-directed goals are presented, and when complete, unlocking new paths of progression. At its heart, *KSP* is a game that takes complex engineering and scientific issues like interstellar probes, rocket science, and interplanetary robotic or manned missions and simplifies them enough to provide a broader entry point for the mass market without sacrificing sufficient fidelity to physics.

KSP is not just a game that is well crafted technically, but it is also an engaging game. An engaging game is a game which embraces the core elements of the

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psychological phenomena of flow [5]. While the identified qualities of flow cover everything from voluntary participation and temporal experiences, the qualities as they relate to games have been simplified down to four specific qualities [1]:

- Explicit Goals with Easy to Follow Rules
- Attainable Goals
- Clear and Usable feedback
- Minimize distraction from the experience

These same qualities are discussed by scholars and developers alike [4, 9, 10, 13, 16] when they talk about effective and engaging game design. The definitions offered, regardless of their origin, all address the above four points, weighting some points of greater importance than others. Regardless of their weighting, the above elements relate directly to the concept of flow, and in some cases, overlap. The qualities of flow [5] can be summarized as:

- Clear and immediate feedback
- Capacity for deep concentration
- Balance between skill and challenge
- User agency
- Effortlessness
- Altered perception of time
- Rewarding as activity and goal
- Complete intellectual investment

While *KSP* is a game designed to get its player into a state of flow, and thereby engaging, it is also an inherently educational game. While not explicitly educational, *KSP* does adhere to specific learning principles, per Gee [7], of games by creating or doing the following:

- A safe environment for learning and experimentation, where the player can make real choices and probe the boundaries of the simulation.
- Incrementally teach the player the skills and content to ensure mastery of the game rules and content and encourage self-determination.
- Allow for the creation of Affinity Groups, where players are more than just insiders to the game, but can become masters and share their information with others.

These elements have the potential to arise out of any well designed digital game, but are they vital to creating an engaging educational experience.

2 Digital Games, Flow and Playfulness

2.1 Digital Games and Flow

The concept of flow is directly related to games of all types. Often, players of sports like baseball or basketball talk about being in the zone. This idiom commonly describes being extremely so focused on the task at hand as part of the larger game that success seems to the outside viewer, as automatic. When players enter into a state of flow, they are in the zone, and are entering into the optimal state of play for that game.

The definition of a game varies and continues to serve as a point of contention amongst researchers and developers alike. Roger Caillois' [2] six qualities of a game remains relevant to everything from physical sport to digital games, as modern developers and theorists have sought to further quantify or take a more granular look at how digital game specifically fit into the greater ecology of games. Some developers couch it specifically in terms of an "active agent against whom you compete" [4], which is potentially subjective in its scope as it assumes that the active agent is either another player or a sufficiently challenging artificial intelligence. Others such as Juul [9] and Koster [10] have attempted to more generalize the definition of game to be retroactively inclusive, deriving a definition that encompasses everything from a first person shooter to puzzles and simulations. For the purposes of this analysis, a game consists of "a goal, rules, a feedback system, and voluntary participation" [13].

Csikzentmihalyai [5] defines flow as "a feeling of complete and energized focus in an activity, with a high level of enjoyment and fulfillment". Built on that and in terms of games, Schell [16] defines flow as a "state of sustained focus, pleasure and enjoyment". A game can get a player into flow, or into the zone, if they successfully balance between an ever increasing challenge with ever increasing cumulative skill of the player. This relationship can best be thought of a sine wave (see Fig. 1), constantly moving toward anxiety and then back toward boredom and back again.

Therefore, as long as the design of the game keeps one from becoming too anxious or too bored, then the player has a greater chance of getting into a state of flow and becoming engaged by the game. *KSP* is most definitely a game: players are tasked with goals that are enforced by rules. These rules vary depending on the game type. The player then receives feedback as they work to achieve the goals to advance through the game. Most of all, people are playing the game voluntarily and creating a dedicated community of practice and online affinity spaces for players of all skill levels to utilize and learn from as they continue their attempts at exploration and play.

2.2 Flow, Playfulness, and Good Learning in Games

The pleasure framework, as proposed by Costello and Edmonds [3] outlines a framework by which developers and designers of interactive art can better quantify and subsequently design pleasurable experiences. Games of all sorts, digital and analog, can be considered interactive art, especially if we consider the definition as proposed above. In the case of what constitutes the game, interactivity is an assumed element of the definition, where players struggle to achieve a goal while working within and against the rules of the game. If one considers that player participants in games also, per Costello and Edmonds, "adopt an active role in order for this [interactive] experience to occur"[1] by struggling with and against the rules to achieve the defined goal. Therefore, the playful experience framework [3], or PLEX, is a suitable framework by which to

[1] See p. 1 of A Study in Play, Pleasure and Interaction Design.

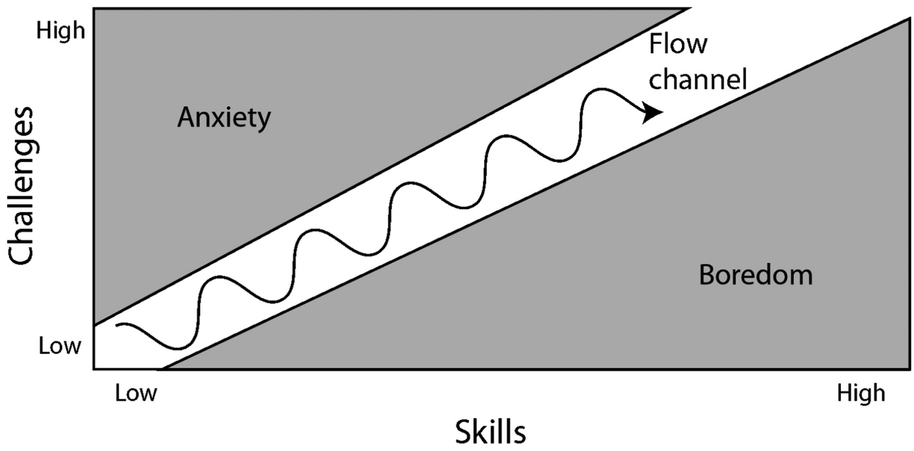

Fig. 1. Game Players within the Flow Channel [16]

judge the playfulness not just of interactive art, but of interactive digital and analog games.

PLEX is a series of categories that describe a broad range of activities through which interactive art can be evaluated. These activities range from the physical to the psychological and can easily be applied onto any sort of interactive art or technology specifically designed to encourage or foster audience or user interaction. These qualities are:

- Creation: The power to create something while interacting with the work.
- Exploration: The power of engaging with unknown situations.
- Discovery: Giving participants agency in solving a problem within the context of the work.
- Difficulty: Giving participants agency to learn a skill to overcome a challenge presented as part of the interactive experience.
- Competition: Giving participants agency to achieve a defined goal, either against the work itself or against other participants directly or indirectly.
- Danger: The work evoking a sense of fear or risk taking as part of the experience.
- Captivation: The feeling of being entranced or controlled by the interactive experience.
- Sensation: Haptic feedback as part of the interactive experience.
- Sympathy: Evoking emotion through the interactive experience.
- Simulation: The interactive experience is based on a real-life situation.
- Fantasy: Engaging with creatures or elements of fantasy or make-believe.
- Camaraderie: The interactive experience engenders positive social experiences with other participants.
- Subversion: The experience engenders pleasure from subverting the rules, whether that be cultural, social, or the interactive experience rules.

The qualities of playfulness outlined in the PLEX are cited as elements that overlay directly with the concepts outlined by Caillois but also Csikzentmihalyai, illustrating overlaps between the three structures.

For Caillois, per Fig. 2 below, overlap occurs across the four elements of games pairing with five elements of the framework. It is worth noting that Caillois was speaking of analog games and sports; his work predates the digital game by several decades.

For Csikzentmihalyai, per Fig. 3, qualities of flow theory span multiple elements of the framework. By combining the two lists, a set of qualities begin to isolate what could be considered good game design in general. Part of this analysis needs to account for Gee [7] and the learning qualities that he cites as being indicative of good game design that inspires good learning. These learning qualities draws directly from flow theory. While flow began to formulate around the time of the digital game boom, it was not conceived originally as something experienced by players of games. Only after the rise of digital games was flow theory applied to player experiences.

If we were to qualify qualities of good game design that facilitate learning per Gee and map it against the PLEX framework, the following links are made (Fig. 4):

The concepts of learning and identity, listed above in Fig. 3, outline the capacity for interactive games to not only create an alternate world that the participate experiences through the means of digital simulation, but to give the player agency to create their own identity. This identity may mirror their real world identity, or it may be something completely different, but it is through the creation of this identity that is both self-directed, projected and embodied that allows reflection of learned information. The semiotic principle is the ability to look across multiple semiotic systems as a complex whole, which involves the player engaging with and determining the affordances of the algorithmic systems presented as the digital game. Situated meaning and learning covers the process of using interactivity to discover new information through the course of play. Telling and doing covers a large amount of the PLEX, as the elements of the PLEX overlap with the core experiences of playing an interactive, digital game. Cultural models deal with establishing accurate content, agency, and semiotics of the game content and the ability for users to not just engage with it, but do so reflectively. Finally, the social mind brings the concept of learning in digital games back to learning being an inherently social activity[2].

The PLEX Framework overlaps with established frameworks, assumptions and definitions as to the constitution of good game design by both academics and professional developers. When we take all three frameworks together, we can see that there is some overlap, represented by the dotted line, with the elements of 'problem solving' and 'risk and chance' from Csikzentmihalyai, Situated Meaning and Learning and Telling and Doing from Gee and Discovery, Difficulty, Creation, Danger and Captivation from the PLEX framework. It is in these elements that, arguably, gameplay occurs in entertainment or educational focused games. *KSP* is a professionally developed digital game that provides a compelling learning experience, encouraging players to indulge in serious scientific and engineering principles. It accomplishes this through

[2] This is a simplified summary. For more see [7] in its entirety.

Caillois	PLEX Framework
Competition	Competition
Chance	Danger, Captivation
Vertigo	Sensation
Simulation	Simulation

Fig. 2. Caillois and the PLEX Framework [3]

Csikzentmihalyai	PLEX Framework
Problem Solving	Discovery, Difficulty
Competition	Competition
Risk & Chance	Danger, Captivation
Creative	Simulation, Fantasy
Friendship & Relaxation	Camaraderie

Fig. 3. Csikzentmihalyai and the PLEX Framework [3]

Gee	PLEX Framework
Learning and Identity	Competition
Semiotic Principle	Exploration
Situated Meaning and Learning	Discovery
Telling and Doing	Difficulty, Creation, Danger, Captivation
Cultural Models	Simulation
The Social Mind	Camaraderie

Fig. 4. Gee [6] and the PLEX Framework [3]

not just good game design, which evokes engagement and participation, but it also generates a playful experience that encourages participants to engage with several elements of the PLEX framework simultaneously.

3 Sandboxes and Self-Discovery

KSP is built around several different game modes. The sandbox game mode is a freeform mode giving players access to all of the content of the game. This mode was originally provided when the game launched, allowing players full access to the various components needed to build a variety of drones, robots, as well as manned and unmanned aircraft and spacecraft. The success or failure of missions is largely dependent on the survival of the craft, the skill of the player to pilot their created vehicle, and the capacity to achieve the self-directed goal established by the player for their own mission.

This sandbox mode is useful beyond utilizing the game as an electronic toy, such as *SimCity* [12], where goals are sufficiently broad to encourage a more pure form of play that is undirected and abides by more classical definitions of the term. Sandbox mode here provides a safe space to refine not just vehicle designs, but also to get a firm grasp on the complexities of piloting vehicles within a space where there is little to no penalty for failure. In this capacity, *KSP* is giving the player a chance to explore the game space on their own terms, embracing Gee's [7] discovery principle, which states that "Overt telling is kept to a well-thought-out minimum, allowing ample opportunity for the learner to experiment and make discoveries."[3], thereby allowing the player to "to experiment and make discoveries" at their own pace. Learning to pilot a simulated rocket that has enough power to achieve a stable orbit within the game is a challenge, particularly as one must navigate several different screens to plan the orbit and project that plan into the user interface while the rocket is in flight. The tools for doing this are provided to the player, but they require interaction to learn and any sort of instruction or tutorial is eliminated entirely and encourages player experimentation. The game mode encourages the player to test, through trial and error, new rocket designs while simultaneously pushing the boundaries of the game without punishment beyond the time sunk into the previous and current designs. This lack of penalty allows the player to explore optimal designs and mechanical configurations for their experimental vehicles and determine if they will meet their self-directed challenge. If the rocket does not, then the player is free to modify their vehicle until it can attain their goal, or they can destroy it entirely and start from scratch. The player can also revise their internal goal, and change the requirements to either suit the existing design or consider a new challenge to tackle with the existing rocket design.

In the sandbox mode gameplay variant, all goals provided to the player are intrinsic goals. This increases the chance that the player will enter into flow because the parameters of the goal are established by the player themselves and the act of play provides the award [14]. By placing the player in control of what they need to do, the goal can be modified, which "results in high-quality learning and creativity" [15]. This mode allows players to learn the interface without time or mission constraints, as the penalties for failure or modifying the mission is moot. This allows the players to understand the feedback as presented to the player within the context of the game. By allowing the players to self-direct and understand the interface, they can filter out unnecessary information not just as presented in the game that is moot to their goals, but can begin to assimilate the information presented and understand how to apply them during more difficult or directed scenarios and more easily get into a state of flow.

When we overlay the PLEX framework, the sandbox mode offers elements of nearly every aspect of the framework elements as listed in Fig. 5. All of this is contingent on the situation of play, of course, but by far the primary elements we see from PLEX are creation, exploration and discovery. While these elements assume a specific type of player, it is worth noting that the sandbox-style of game gives the ultimate amount of freedom to the player to do whatever they like within the constraints of the game systems. The sandbox mode provides open access to all game content without any sort of rule-based structure, allowing players to construct their own airplanes,

[3] For a full description of Gee's discovery principle, see Chap. 5 of *What Video Games have to Teach Us about Learning and Literacy.*

rockets, and other space vehicles, regardless of their efficacy. This mode allows players to do the following:

- discover how the various systems within the game work with little repercussion
- make modifications to the user interface to suit their attention
- learn how to understand the feedback provided by the game
- how to translate that into actions that will either positively or negatively impact their designs.

Sandbox mode also allows players to explore more than the mechanical systems presented by the game. Players have the agency to discover how these various systems, or semiotic domain, interact and practice developing and creating their own rockets in preparation for playing through the more limited, mission-driven aspects of the game. The exploration can also be literal, as players can explore the world of Kerbin, the Earth proxy within the game, or the entire solar system including the nearest astral body, the Mun, Kerbin's moon. If we take flow theory and the concept of a good game as described above, then captivation is entirely possible, as players generate intrinsic goals for their creations, from orbital insertion of a new satellite or landing a member of their astronaut corps on the distant Mun.

Because it is player driven, players in sandbox mode can engage with other elements listed in Fig. 5, like simulation, difficulty and camaraderie, but these are all highly contextual on where, when and how the player is engaging with the game software. When it comes to intrinsic motivation as part of the sandbox play experience, things like simulation and difficulty are not something explicit in the game mode. The sandbox is less concerned with extrinsic rules and motivations for the player, relying on self-motivated players to create their own meta-tasks within the game. The same with difficulty, where the difficulty is related more to intrinsically generated goals by the player. The challenge is self-imposed, and given the ease at which players can restart missions, difficulty becomes less about overcoming computer-imposed obstacles and more about player-defined challenges and obstacles.

Finally, the sandbox also offers the most flexible application in an educational environment by students in primary and secondary education. Teachers can provide the goals and missions that are not provided by the game, while providing a direction with the interface used in the planning and successful construction of rockets. Because the game lacks a specific tutorial, normally used to teach new players how to play the game, the sandbox mode gives the player and the instructor the tools needed to not just create a tutorial for a diverse number of age groups, but then hands these players a vast digital simulated scientific game where players can leverage information imparted by instructors and apply it within the game itself in a consequence-free environment. By doing this, *KSP* lays the ground work for an educational affinity space. In this affinity space, *KSP* creates the feeling of managing a space program, where the teacher and students can encourage and resource their own creativity and productivity [6]. If the players successfully apply the information generated within the affinity space, then their mission will be a success. If their mission is a failure, students join together in this affinity space to discover what went wrong and then retest their designs by resetting the game world and executing the mission again. The game provides a space in which students can explore, experiment and apply information that has been taught to them

Csikzentmihalyai	Gee	PLEX Framework
Competition	Learning and Identity	Competition
	Semiotic Principle	Exploration
Problem Solving	Situated Meaning and Learning	Discovery
Risk and Chance	Telling and Doing	Difficulty, Creation, Danger, Captivation
Creative	Cultural Models	Simulation
Friendship & Relaxation	The Social Mind	Camaraderie

Fig. 5. Gee [6], Csikzentmihalyai and the PLEX Framework [3]

without the necessity of grades or testing as the game is testing and retesting the students and completion of the goal illustrates a pass/fail state.

4 Achievement and Science

The second game mode for *KSP* is referred to as science mode. In this mode, the player is constrained as to what components are available to them based on the amount of research they perform on each mission. This mode places constraints on vehicle components by requiring players to pack their designs with a variety of unique scientific gear that generate points which can be spent unlocking new technologies. These new technologies then unlock new missions and new chances to generate more science points, creating an extrinsic motivation for the player. These awards illustrate compliance with the rules of the game and successful assimilation of game feedback, where the player can "obtain an externally imposed reward contingency" [15]. These rewards funnel the player into a series of challenges which tests their mission design, vehicle design and vehicle piloting capabilities. This is also a test of the basic application of physics upon which the game is designed. Science mode also serves to prevent information overload as players are introduced to vehicle components and capabilities in small chunks, allowing newer players to more gradually build their version of *KSP* by limiting not just their mission goals, but their vehicle capabilities to more manageable chunks.

This reduction of capabilities is useful for new players. By providing a subset of information, *KSP* is allowing players to learn the game and its mechanics slowly so that "by the time new players are aware of what basic skills in a given type of game…they have already mastered them" [7][4]. By reducing the number of components available to the player, the amount of information that needs to be processed in order to complete the provided missions is reduced. This allows the player to increase the amount of attention then can give to their goal rather than spending time sorting through a large

[4] For a full description, see pp. 135–136 in Chap. 5 of *What Video Games have to Teach Us about Learning and Literacy.*

variety of component types and capabilities which may far exceed the needs of the goals presented by the game. This ensures that the learning situation is based upon Gee's [7] incremental principle[5].

With PLEX, we see the invert the sandbox above. Instead of intrinsic self-directed motivation for the player, the qualities of PLEX become constrained by the gameplay systems. In this case, the simulation becomes highly restricted and bound by the rules of the game and beyond simply a representation of the physical world. While elements of creation are still leveraged, these are constrained by limitations to available parts, meaning players must do more with less until they achieve sufficient points in various categories to acquire new technologies and new rocket or vehicle parts. So follows, discovery and exploration are now directed toward achieving goals as determined by part research, gently directing the player extrinsically. Flow is still possible, but *KSP* becomes a different type of playful experience. Here the elements of competition, simulation, difficulty and danger come to the fore.

These elements are a mirror of most single player-focused digital games. Competition is indirect. Players do not play with each other, but they are competing against the challenges that have been intentionally designed and algorithmically enforced by the computer. That isn't to say that, in the right context, that competition cannot occur, but these are all external to the challenges presented by the game. Players may choose to race to the Mun if played in a computer lab or an internet café, but this does not change the challenges outside of science mode. Instead, players are competing against themselves and the game. They need to work within the constraints presented by the game challenges and their own capabilities, establishing a specific difficulty that constrains and challenges the player; a key elements of flow. The games challenges are explicitly designed to be difficult. Per flow, as illustrated in Fig. 1, the game provides a balance between challenge and skill. Initial parts provided allow players to create simple vehicles with limited capabilities. As they complete challenges, the new parts are unlocked and new capabilities allow for more complex vehicles. Danger also comes not to the player directly, but to the player avatar and representation in the game. In this case, losses of astronauts occurs, but equipment is replaced easily. Here, the game rewards engaging with danger as it relates to the flow channel. Performing risky designs that meet the challenges is a method of intrinsic motivation in response to the extrinsic motivation of the game.

Science mode is a different style of game than sandbox mode, but still an element that evokes a playful experience. The experience, in this case, is one geared toward flow, so it follows more faithfully with the elements and comparisons made above. That is not to say that the sandbox mode is not playful; they are both obviously playful. The type of playfulness that is fostered is different, based on either player-centered or game-centered challenges. Playfulness then becomes a choice between playing with the game systems or playing the game and within the constraints of a more limited experience. Both are certainly valid, and presents an interesting dichotomy in an educational context. Students and teachers alike can use the limitations of science mode to emphasize specific points about scientific inquiry and engineering, or they can use or

[5] See p. 137 in Chap. 5 of *What Video Games have to Teach Us about Learning and Literacy.*

use the sandbox to emphasize engaging with the simulation of astrophysics and aerospace engineering.

5 An Affinity for Rockets

KSP is a game intended to be played alone. It does not have an explicit networking component, so as players interact with the game, they are intended to do so solo. While this certainly fits with the classic idea of school work, experts who play this game and any game for enough time and with enough skill will become a member of the games semiotic domain. It is through this semiotic domain and the affinity groups that they generate that students are better to teach each other how to optimize their experience in the game.

A semiotic domain is defined as "an area or set of activities where people think, act, and value in certain ways" [7]. Most digital games like *KSP* qualify as individual semiotic domains. *KSP* possess a unique set of modalities (images, sounds, and information), which can be grouped together as a common set of signs that are used "to communicate distinctive types of meanings" [7]. Learning this information and being fully involved in the semiotic domain is how you learn to play the game as well as internalize the information presented.

KSP, by being a semiotic domain, also generates a community of players either locally or through the internet that has been termed an affinity group. Members of these groups are insiders who "recognize certain ways of thinking, acting, interacting, valuing, and believing as more or less" [7] the same. Every classroom where *KSP* is played has the potential to become a specific instance of an affinity space, joining other affinity spaces that already exist for the game, such as the *KSP* wiki [17]. The wiki provides another tool in the application of distributed cognition and knowledge accumulation [8] around playing the game, providing a central focus not just for individual players to seek out information on how to complete tasks in the game, but as a means to contribute their own information to the pool of knowledge around the game.

These affinity spaces, whether online or in the classroom, serve as means of bonding between the students toward their common endeavor of playing the game and the objectives contained within either by the game or by the instructor. In the vernacular of the PLEX, this is camaraderie. As defined in the PLEX, camaraderie is "the pleasure of developing a sense of friendship, fellowship or intimacy with someone" [3], and these affinity spaces serve as a means to meet and engage with, either in the classroom or mediated by the internet, allows the formation of a community practice by players and teachers alike. Here, teachers and students become both learners and producers. To play *KSP*, the student needs to not just learn the basics of physics to create their rockets, but they need apply what they have learned and produce rockets that achieve the goals either created by the game or intrinsically by the player themselves. It is through these affinity spaces that any information missing from the participants' repertoire of knowledge can be supplemented and subsequently applied.

The extrinsic goals provided by the game also provide instructors and students alike a series of concrete goals to attain. This conforms to the expected role of the instructor and the game as a tool for instruction, as meeting the goals serves as a test to ensure proper instruction has not just taken place, but the information has been successfully applied. Extrinsic goals can undermine intrinsic motivation of the student [11] if unsuccessfully applies, particularly if the student loses a sense of psychological self-determination [14].

6 Conclusion

Games and education are at a crossroads. Digital games are becoming more powerful with increasingly complex and effective technology, with handheld phones like the iPhone coming with more memory and processing power than home computers and consoles that were modern a decade ago. As game content has become far more intertwined across multiple media, so has the player demand for more diverse and unique game experiences delivered with amount of polish and quality. Educational games will be compared against entertainment-focused games. If educational games do not measure up in terms of engagement and design principles that are used in creating digital games, they will be neglected and ignored by the students. The most obvious and well documented way to get students engaged with an educational game is to ensure that the game is well designed and therefore engaging. The PLEX framework provides a method by which all games can be analyzed. This is especially important in educational contexts, as stakeholders such as faculty, parents and administration view the value and use of explicitly entertainment focused titles in educational contexts skeptically. By providing for a set of criteria that elaborates on the value of the game as means of engagement in an educational context, it becomes easier to not only explain its learning goals and purposes. This data will allow designers and educators to better leverage these games in the classroom and meet students in familiar territory. By being inclusive of educational digital games like *KSP*, educators allow students to exceed and excel, rising over those "who never confront challenge and frustration, who never acquire new styles of learning, and who never face failure squarely" [6].

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