Serious Games integration into the Engineering Curriculum – A Game-Based Learning Approach to Power Systems Analysis

***Abstract* -- Essential to the toolset of modern power engineers are the business environment knowledge, an appreciation for customer service/satisfaction as well as the ability to analyze, negotiate and articulate clearly with technical and non-technical personnel. Whilst most engineering oriented universities recognize the role of practical experience, challenges exist with the students' ability to translate the theoretical into practical knowledge. This paper investigates the application of the game-based learning (GBL) instructional method, as an alternative method of enhancing the practical application of course delivery, through the integration of business thinking principles into the final year undergraduate power engineering curriculum. IBM's Innov8: CityOne Game was chosen as the game of preference as it embedded core course content material via a serious game. The Game was administered to two consecutive cohorts (2012 and 2013) of the level three undergraduate course Power System Analysis. A qualitative and quantitative review of both cohorts' feedback and performance are individually analysed and compared.**

***Index Terms* -- Power systems planning, power engineering education, educational technology, games.**

I. Introduction

A. Power Engineering Curriculum

The undergraduate power engineering curriculum in the Department of Electrical & Computer Engineering at The University of the West Indies (UWI), St Augustine Campus is covered by seven three credit courses delivered over the three years of the program. Two of these courses are delivered sequentially in levels one and two and the final five courses at level three. Power System Analysis (PSA) is one of these level three courses. PSA provides students with comprehensive material about the operation and analysis of power systems, covering the major topics likely to be encountered by the power systems engineer. The aims of PSA are to:

- Provide knowledge to students about modeling and simulation of power systems in steady or pseudo-steady state and the computational tools required to solve and analyze these models.
- Familiarize students with engineering techniques of power system analysis used in the industry today for the operation, planning and design of power systems.
- Familiarize students with the use of software based modern power system analysis tools.

PSA is delivered over a period of 30 one hour lectures and six hours of tutorials covering the following topics:

- Introduction to PSA: History and future of power systems
- Transmission line: Operation and modeling
- Load flow analysis: Admittance matrices, Gauss Seidel, Newton Raphson
- Fault analysis: Impedance matrices, symmetrical & asymmetrical faults
- Transformers: Operation and modeling
- Generators: Economic operation and transient stability

B. Introducing Serious Games

Embracing best practice principles whilst continually improving the structure and delivery of this course was paramount in keeping the course refreshingly updated. The next challenge was to create an engaging and effective approach for students to grasp the inter-connectivity between the core underpinnings of power systems operation and the broader business context. A serious game was introduced which focused on the essential aspects of business analysis while maintaining inter-connectedness of the core elements of the course. This newly introduced gaming element was fashioned into 5% of the 25% coursework weighting as outlined in

Table .

TABLE I: PSA ASSESSMENT ARTIFACTS DETAILS

Assessment Artifact	Must Pass	Weighting %	Qty
Final Written Examination	No	75	1
Computer Simulation Exercises (CSE)	No	15	3
Assignment	No	5	1
Game	No	5	1
Total		100	6

The CSEs highlighted in

Table were administered using MATLAB and POWERWORLD software packages. These were 'take-home' exercises with an 18-24 day period between issuance and submission. The 5% assignment exercises changed annually between written calculation exercises and powerpoint presentations on varied PSA topics.

The introduction of gaming for educational purposes has, over the years, grown in relevance as an educational tool. Games such as City One were designed for education and problem solving purposes specifically focusing on illustrating the impact of technology in creating smarter cities. Participants focused on four (4) central components; energy, water, retail and financial services utilizing expert recommendations, to integrate effective solutions within a game-based learning environment. The orientation of play for decision-making was evaluated based on process metrics, business analytics, smart grid technologies and integrated supply chain systems. The challenges facing city prosperity balanced a tiered ecosystem with continuous satisfaction indicators based on inhabitants' welfare, business development and the environment within a limited budget.

Table I provides an overview of the assessments and corresponding links to assessment artifacts. The introduction of the game highlighted an evolution in the LOs with exposure to the holistic power system operation (broadly characterized under LO4). This has been documented for inclusion.

TABLE I. LINKING ASSESSMENT ARTIFACTS TO LEARNING OBJECTIVES

Assessment Artifacts	Course LOs Covered						Details
	LO1	LO2	LO3	LO4	LO5	LO6	
CSE 1	✓		✓				Power flow analysis
CSE 2	✓		✓	✓	✓		Fault analysis
CSE 3		✓	✓	✓			Economic dispatch
Assessment	✓	✓					Topic variation
Game				✓			Power systems
Final Written Examination	✓	✓	✓	✓	✓	✓	3 hr

Games as a source of learning are becoming more prevalent within the higher education environment. The focal point of games is their ability to provide a degree of engagement and immersion which enhance the overall student experience (Brown, 2004). The concept of game-based learning (GBL) participants are exposed to higher levels of engagement (Annetta, 2008) and represents the nexus of semi-autonomous learning, inclusive of the use of technology, as a form of pedagogical praxis. Thus (GBL) leverages the power of play to improve student learning/performance.

The GBL project within the Faculty of Engineering of The University of the West Indies, St. Augustine Campus is a two year old initiative which initially commenced in 2012. The concept was introduced to provide an integrated approach to the subject domain of PSA and its integration with business decision making. The game was focused on decision-based play aimed at assessing students' abilities to effect business strategies based on their PSA course within an urban planning context and as such translate basic theory into action. The use of GBL methodology for learning and assessment is not uncommon, but it must be emphasized that this was a novel initiative within the department.

II. SERIOUS GAMES/GAME-BASED LEARNING

Adoption of serious gaming presents an interesting challenge as the barrier to entry for advanced learning technology products are still relatively high, coupled with their cost of development and market-introduction. Those institutions which integrate next generation learning technologies into their pedagogical architecture gain significant advantage over their peers through the various elements of collaboration, engagement and learning which these games can provide. Hence, education institutions wishing to adopt serious gaming need to identify strategies which position their pedagogical endeavours to ensure the development of appropriate strategies for success.

Digital game-based learning (DGBL) is an instructional method that incorporates educational content or learning principles into video games with the goal of engaging learners. Applications of digital game-based learning draw upon the constructivist theory of education. Constructivist theory is the basis for active learning, emphasized by hands-on, activity-based teaching/learning where students develop their own frame of thought (Keengwe et al., 2009). Drawing from the constructivist theory of education, DGBL connects educational content with computer or video games and can be used in almost all subjects and skill levels. A constructivist context provides a possible answer to one of the challenges faced in the classroom with today's digital natives, i.e. how to teach learners with backgrounds different from their own (Keengwe et al., 2009).

The higher education curriculum needs re-engineering of its pedagogical innovativeness to improve the delivered content specifically in complex subject domains given the challenges of practice. Institutionally, curriculum approaches at UWI have been predominantly Socratic, centered on academic instruction with the students as passive recipients. Student's contributions to content flexibility, delivery or its mode of gestation are minimal. Thus the potential for better strategies for learner retention are still in their infancy stages. Consequently, it is important to contextualize the attributes of GBL to improve understanding of this approach for course enhancement.

Technology is forcing rapid changes in the academic landscape and with it modalities of content delivery. As academic environments continually struggle to keep up with these advancements, especially as it relates to instructional delivery amongst digital natives (Prensky, 2001), the need for tools that support greater learner integration becomes mandatory.

A. Attributes of Game-Based Learning

Games provide a different pedagogical perspective within a higher education context. They are not a natural fit to the pedagogical landscape but represent two critical factors which need to be considered:

- They are impactful
- They are emerging as a potential source of disruption in current teaching models

Given these two factors, some attributes of games are as follows:

- Task specific
- Ability to concentrate on the task (deep immersion)
- Task have clear goals
- They provide immediate feedback
- They provide a high degree of autonomy

These attributes correlate to curricula and align to content design specifically when considered in the context of traditional course delivery. The impact-correlation factor between game-based learning and higher education lies in the increased engagement, learner retention, reduction in cognitive load and increased student participation and attendance. These represent key factors for consideration in courses such as PSA in Electrical Engineering as they act as enablers for higher curricula participant engagement (Squire, 2003).

Ashley (2007) (Ashley.R, 2007) speaks to the future of games in education and as such frames game adoption in formal education within a problem-type taxonomy. Treating with the deconstruction of the PSA course, via the introduction of game-based problem events split into atomic units, can greatly assist in content design and delivery. This will further assist in deciding what type(s) of interventions (game or other) will more appropriately fit the learning goals and objectives of the curriculum.

The relevance of GBL in Electrical Engineering shares close linkages to the theory of play and learner identity. Important components of learner-centered models are the consideration of learning characteristic, interspersed with sub-variable such as learning styles, abilities and other antecedents that make each learner unique (Gollnick and Chinn, 2002). The field of engineering is premised on inquiry, experimentation, collaboration and experience. As such, the need to engage students in a manner which bears relevance to these tenets are enhanced by both the process of play and the encouragement of discovery through the game play process. The use of a GBL approach contrasts with the traditional teacher-led where students have limited or no control but remain passive recipients diminishing the valuable contribution learner centered approaches can provide using games to discover patterns, concepts and other relevant data (Squire, 2003). There is an underlying imperative for the use of video games to support student exploration through micro-worlds or as construction tools consistent with emerging paradigms of learning (Papert, 1980, Rieber, 1996).

According to a study by the National Education Association, Washington DC (Narode et al., 1987) science is a field in which trial & error and experimentation are fundamental for hypothesis testing. However, despite our best efforts we teach students to memorize theory through rote approaches without actually experiencing the process. If we took the analogy of sports where play is an integral part of the learning process, students would through the use of play (games) improve their skills through coaching and practice. As such the use of a game-based learning approach was a conscious attempt to step away from the Socratic methodology. The choice of a game as a means of reinforcing and expanding conceptual thinking within the PSA course presents an opportunity for an active student driven learning experience benefitting from a process based scientific approach to learning. The contribution of game-based learning to these efforts invokes the student principle of self-monitoring which in turn requires them to engage in higher-order thinking as part of the scientific process.

B. Relevance of Games in Higher Education

While contemporary Caribbean education still persist with traditional chalk and talk modalities, there exists in some quarters a growing appreciation for games as a form of pedagogical practice to support learning. This trend has target audience relevance to students within complex subject domains such as PSA as they represent Generation C (Connected) (Friedrich et al., 2011), i.e. the net generation. These next generation students are consummate users of content, digital devices and gaming. Their perception of technology is rooted not in adoption but in a natural orientation. The requirement to connect on their own terms, in the classroom and elsewhere presents an issue of relevance for higher education's survival as they have an abundant availability of substitutes from which to choose for learning. Students, are naturally responsive to storytelling as they create learner-centred, learner-guided environments (Dzinory, 2005). Higher education can take advantage of games as they allow the students freedom to explore, experiment and adapt learning within their own environmental context and speed.

DGBL allows educators to gain a more concrete understanding of leaner dynamics through the lenses of educators as:

- Instructor
- Guide
- Explorer and,
- Playmaker

A concept articulated by Arnab *et al* (Arnab et al., 2012) envisages that the teacher becomes complementary and positions the knowledge not as a forced procedure associated with the overall learning process but as reinforcement of the existing theoretical knowledge.

III. Factors that Impact PSA using GBL

Whilst the approach to the use of games with PSA and as a tool within the department for learner improvement and conceptual understanding is new, there are three factors which need to be understood as part of the validation process for the use of this methodology. They are:

- Cognitive load theory
- Flow theory
- Engagement theory

A. Cognitive Load Theory

Cognitive Load Theory (CLT) is concerned with the manner in which cognitive resources are focused and used during learning and problem solving. Many learning and problem solving procedures, encouraged by instructional formats, result in activities by participants far removed from the task at hand or lost soon thereafter post learning. This theory's relevance to this paper rests in its integration and impact to be utilized as a measurement tool within an instructional design context. Cognitive load represents an excellent starting point for measuring students' understanding of PSA due to its ability to:

- Create problem solving methods that avoid means-ends approaches imposing a heavy working memory load, by using goal-free problems or worked examples. This approach allows academics to measure the degree of cognitive processing naturally built in as a result of re-focusing on instructional design.
- Allows for measurement by eliminating the working memory load associated with having to mentally integrate several sources of information by physically integrating those sources of information.
- Allows for increase working memory capacity by using auditory as well as visual information under conditions where both sources of information are essential, i.e. game play and visual integration of all the curriculum elements allows for easy recall due to the flow experience.

B. Flow Theory

Flow theory (Csikszentmihalyi, 1975) is the second tool and can best be defined as the mental state of operation in which a person in an activity is fully immersed in a feeling of energized focus, full involvement, and success in the process of the activity. The concept was first defined by Mihály Csíkszentmihályi, the positive psychologist in the 1960's. The value of flow as a measurement tool rests in its defined components which, if appropriately contextualized, lead to both integration of game-enhanced learning in higher education and more engaging curriculum experience for its Generation C audience. The initial components as defined by Csíkszentmihályi (Csikszentmihalyi, 1975) are as follows:

- Control
- Attention
- Curiosity
- Intrinsic interest

The relevance of these dimensions to game-enhanced learning, curriculum integration and measurement are inextricably linked. When translated into re-engineering of the PSA curriculum within higher education the overarching philosophies of games are inherent in the flow experience as students experience deeper-richer learning.

C. Engagement Theory

Finally, for any of the above to be adopted there must exist shifting paradigms of the human element. Academic institutions are generally slow to change and struggling to influence the status quo is usually met with much resistance. Game-enhanced learning has the potential to provide a high degree of engagement and as such would attract greater student interest simply because it appears to be fun vs. traditional brick and mortar teaching approaches.

Given the philosophy of engagement, experimentation with the PSA curriculum process offers better levels of enticement as evidenced through student responsiveness and these activities created a high degree of engagement. Similarly, game-enhanced learning through its interactivity, multi-dimensionality and design creates an environment for greater engagement in the development of curriculum by creating stronger linkages through:

- Collaboration
- A problem based orientation and
- Leveraging external focus, i.e. creating an opportunity for interactions external to the classroom which build on the theoretical perspectives of the curriculum

IV. METHODOLOGY

IBM's Innov8: CityOne Game was chosen as the game of preference as it embedded core course content material via a serious game. Innov8 was created by IBM as a tool to assist in teaching problem solving for real issues within industry. The CityOne Game, takes the challenge a step further by leveraging various technologies to effect complex change within a large city. Part of the complex change scenario involves the use of smart grids, which made for a natural fit with the power systems course. The target group consisted of students in a level three course, Power System Analysis. The game was administered to two consecutive cohorts (2012 and 2013)

A pre-game session was used to give a brief (approximately 30 minute duration) introducing the game's concepts and the objectives of play within the context of PSA. One week later, a game play session was executed in the Engineering computer laboratory over a two hour period. The target audience age group ranged between 19 – 24 years with the majority being male.

On the day of game play specific instructions were provided as it relates to how the game works, its reward systems and other factors which would impact play outcomes such as earning badges and other bonuses. At the end of the game scores of participants were collected. An online survey using Qualtrics consisting of both open-ended and structured questions was sent to participants approximately two days after completion of the game to ascertain the acquisition of learning outcomes and probe specific aspects of student involvement in and perception of the game.

Preliminary data collection occurred across a relatively broad spectrum, which included; least/most liked features, value of instruction and degree of difficulty within components of the game.

V. Results

The quantitative and qualitative results are captured and analyzed in the following tables and graph. There were 33 students in the 2013 cohort and 26 in the 2012 cohort.

TABLE II: COHORT INFORMATION

Year	**Gender %**	**Mean Age**	**Std-Dev**
2012	M:89, F:11	24	2.03
2013	M:91, F:9	22	0.36

TABLE III: COHORT STATISTICAL RAW SCORE RESULTS

Year	**Mean**	**Median**	**Std-Dev**
2012	193,346	190,000	72,075
2013	635,259	263,484	1,132,726

TABLE IV: COMPARISON OF SUMMARY STATISTICS BASED ON PARTICIPANTS' FEEDBACK AFTER COMPLETING GAME

		2012	**2013**
User friendliness	Extremely	-	20.0%
	User friendly	94.1%	66.7%
	Somewhat	6.0%	10.0%
	Not	-	3.33%
Ease of navigation	Yes	100%	93.3%
	No	0%	6.7%
Least liked feature		Game Instruction 52.9%	Game Duration 43.3%
Most liked feature		Game Content 58.8%	Game Content 53.3%

TABLE V: COMPARISON OF DEGREE OF DIFFICULTY EXPERIENCED BY PARTICIPANTS IN EACH OF THE FOUR COMPONENTS FOR 2012 & 2013 (1- NOT DIFFICULT, 2- AVERAGE, 3- DIFFICULT, 4- VERY DIFFICULT)

	Energy		Water		Retail		Banking		Total	
Degree of Difficulty	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
1	4	7	5	11	0	2	1	4	10	24
2	1	2	5	6	4	11	4	7	14	26
3	3	4	1	5	5	9	5	10	14	28
4	4	13	1	2	5	1	3	8	13	24
Responses	12	26	12	24	14	23	13	29	-	-
Mean Degree of Difficulty	2.6	2.9	1.8	1.9	3.1	2.4	2.8	2.8	-	-

TABLE VI: SELECTED QUALITATIVE COMMENTS FROM PARTICIPANTS

"I enjoyed the game tremendously. On a side note in question 12 I was only allowed to make one selection in each of the columns, as such I was not allowed to express my truest opinion on the difficulty of each component."
"Very nice concept. More flexibility in answers would be an asset as in reality there is no way to tell whether or not decisions will have the intended impact or even the intended magnitude of intended impact. Therefore answers should depend on a greater number of factors, including random statistics for certain decisions."
"In my opinion, the game should brief the user not competent in all fields, on the fundamental purpose of all the sectors."
"Overall, this game was very informative and engaging cannot select the rank on the provided scale above but retail & banking=4."

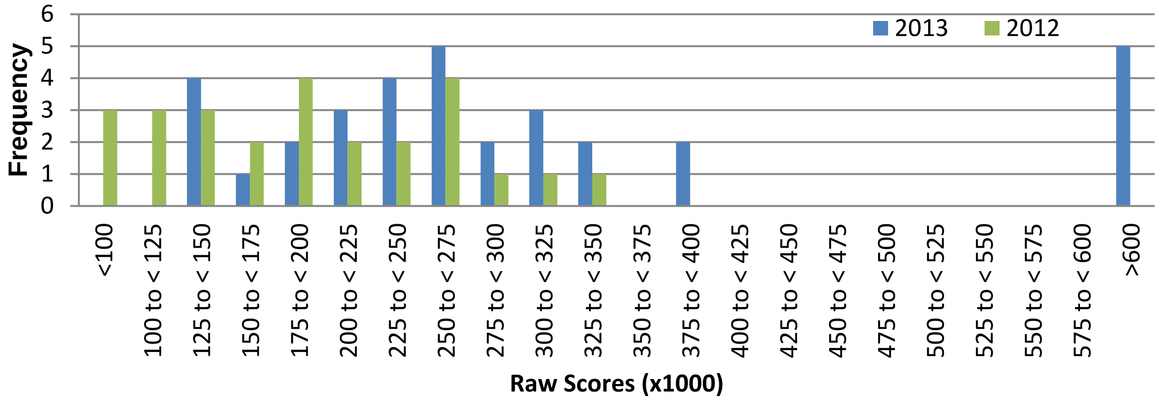

Figure 1: Raw scores for both cohorts illustrating two potential distributions for the 2013 cohort.

TABLE VII: OVERVIEW OF 2012 & 2013 SURVEY RESULTS BASED ON PARTICIPANTS' FEEDBACK

	2012	2013	Variance
Least Liked Feature			
User Interface	-	3.3%	0
Instructions	52.9%	16.7%	0.68
Music/Graphics	32.2%	16.7	0.48
Duration	11.7%	43.3%	0.72
Game Content	-	3.3%	0
Game Navigation	-	16.7	0
Total			
Most Liked Feature			
User Interface	5.9%	13.3%	1.25
Music/Graphics	-	10%	0
Interactivity	35.29	23.33	0.34
Game Content	58.8	53.33	0.9
Game Duration	-	-	
Game Navigation	-	-	
Total			
Value of Instructions			
Very Useless	-	3.5%	0
Useless	23.5%	10.3%	0.56
Neutral	41.2%	27.6%	0.33
Useful	23.5%	48.3%	1.05
Very Useful	11.8%	10.3%	0.13
Total			
Most Difficult Component			
Energy	26.7%	58.6%	1.19
Water	-	10.3%	0
Retail	40%	10.3%	0.74
Banking	6.7%	17.2%	1.56
All of the above	20%	-	0
Unsure	6.7%	-	0
None	-	3.45%	0
Total			

VI. DISCUSSION

Raw score game results revealed potentially two overlapping distributions for the 2013 cohort in

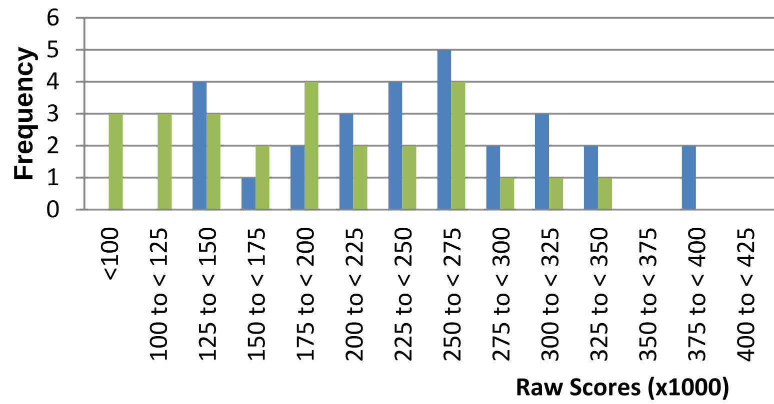

Figure 1 suggesting an external influence linking performance within the gaming environment. This is supported by the significant variation in mean and standard deviation for both cohorts as illustrated in Table III. The median scores were of comparable magnitude relative to the spectrum of raw scores. This suggested some consistency in the technical knowledge of both cohorts.

The 2012 survey revealed 59% satisfaction with the game content (technical and business) and a 35% satisfaction with game interactivity. Participants perceived a higher degree of cognitive load (Sweller, 1988) within the retail component rating its difficulty at 40% followed by the energy oriented decisions at 27%. Qualitative responses pointed to an appreciation for this learning experience, highlighting both exposure to a game-based approach and knowledge gained through play specifically with retail and banking components.

Overall, participants perceived the experience as challenging but highly stimulating. This exercise yielded encouraging student participation and beneficial results. It also provided valuable feedback for further research as it relates to the use of games and their outcomes for possible future inclusion into the power engineering curriculum as an effective complementary instructional methodology.

While the intention of this experiment was purely for the purpose of improvement of the PSA course delivery, there are a few areas worthy of discussion. In most of the categories observed raw scores declined significantly between 2012 and 2013.

Least Liked Feature: Instruction, music and duration of the game were cited as the least liked features of the game between 2012 and 2013. Interestingly, the degree to which appreciation fell in these categories between the one year period was significant viz: instruction (68%), music/graphics (48%) and duration (72%). The result of the significant reduction in the dislike for instruction as in 2013 proved interesting especially since teaching assistants provided instruction in 2013 but in 2012 instruction was delivered by lecturers. Briefing was standard using the same material in both years yet the degree of dislike for instruction reduced significantly. It is strongly suspected that less time was spent on briefing as was the case with academics in 2012. Hence students were able to delve into play more quickly and discover the challenges.

Most Liked Feature: Similar patterns followed with this feature with user interface preference increasing by 125%. This increase may represent a perception by students of an easy to use interface for navigation and play. Familiarity with the use of game interface environments contributed greatly to student decreases in the degree of interactivity (34%) as most would have been familiar from traditional game environments, i.e. (pc and console).As such while a gaming platform may have lacked much of the sophistication of native console environments a relative degree of user interface familiarity allowed for ease of use.

Value of Instruction: 48.3% of respondents found the game useful in 2013 providing a 106% increase in perception compared to the 2012 results. Students expressed a keener understanding of the integration of business concepts and the PSA course and as such were able to derive immediate benefit through play.

Most Difficult Component: The degree of difficulty of individual components was tracked to ascertain challenges participants encountered with novel or existing subject matter. The energy component proved to be the most complex for students despite coming from science and engineering backgrounds. Contributors to the large, unexpected perceived increase in difficulty for the energy (119%) and banking (156%) components and associated reduction in the retail component (-74%) were unidentified but it is postulated given the game's practical nature, students would have experienced some challenges with application of theory.

Overall, whilst the degree of enthusiasm for a GBL approach by students remained high, the authors still need to ponder more deeply trigger and drivers within the game which present challenges or are perceived as motivationally rewarding for play continuity. There is a definite need to explore the data further in the next iteration to ascertain respondents thinking and challenges.

VII. Conclusions

The successful introduction of serious games into the power engineering curriculum at The UWI has created an enthusiastic atmosphere for the fostering of learning. This unconventional mode of delivery satisfied the learning objectives whilst providing increased exposure to non-technical areas. The energy component yielded an unanticipated area of challenge for students but correlates positively with a linkage between exposure to theory and lack of an environment for practical application. Furthermore, it is important to consider that the target audience comprises digital natives whose exposure to technology and by extension games provide a natural fit for experimentation of this nature. This enhanced the PSA student's experience. Preliminary results provide a platform for continue exploration of not just alternative instructional methods that positively impact the (power) engineering curriculum through increase student engagement but also contributes to the emerging body of GBL.

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