Simulation for Dynamical Model of Educational Effectiveness through Gamification

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Abstract. A dynamical model of educational effectiveness through Gamification was introduced. Based on the theories of Game Design Features (GDF), Key Characteristics of a Learning Game (KCLG), a theory of educational environment design model (ARCS), and the theoretical background of Gamification labeled as the MDA framework, four primary factors such as curiosity, challenge, fantasy and control have been originated. By using these four primary factors, the dynamical model for Gamification was developed. In this paper an example for the model is considered and simulated. The examples and simulations make the values and characteristics of the four primary factors meaningful.

Keywords: Gamification, Game Based Learning, DGBL, Learning Game

1 Dynamical Model for the Gamification

Previous papers have proposed a dynamical model for the Gamification of learning [1]. We analyzed the interrelation of dozens of elements from GDF(cool features, fancy graphics, challenging puzzles, and an intriguing setting and story)[2], KCLG(challenge, curiosity, fantasy and control)[3], ARCS(attention, relevance, confidence and satisfaction)[4] and MDA(mechanics, dynamics and aesthetics)[5,6,7] using our empirical techniques, and then extracted Four Primary factors-Curiosity, Challenge, Fantasy and Control - for Educational Effectiveness through the Gamification of learning. We also created a sigmoidal equation for the educational effectiveness of Gamification by analyzing and correlating these factors.

The core idea of the model for educational effectiveness through Gamification as a function of time, \( x(t) \), initiates the comparison with an assumption of educational effectiveness of traditional learning. Assume that the educational effectiveness of the traditional way is solid but steady which is why it is assigned a constant value, \( E_{TW} \).

Based on the assumption above, at the initial stage, the rate of change of educational
effectiveness with respect to time is proportional to \( x(t) \frac{dx(t)}{dt} \approx Gx(t) \) where \( G \) is the growth rate of educational effectiveness through Gamification, and \( x(t) \) will converge on a learning capacity \( L \), \( \frac{dx(t)}{dt} = 0 \) at \( x(t) = L \). The mathematical expression is given by

\[
\frac{dx(t)}{dt} = Gx(t)
\]

(1)

\[
x(t) = \frac{a}{b+ce^{-dt-k}t^k}
\]

(2)

\[
x(t) = ax(t)
\]

(3)

Comparison can be made of equation (1) and (3) with the constant \( d \) as the growth rate of educational effectiveness through Gamification, \( G \). Since the \( Control \) suggests that if the user can dominate the game, more time will be spent in the game, \( d \) can be considered as the \( Control \) in this model. The reciprocal of \( \frac{b}{a} \) is learning capacity, \( L \), in equation (1). Assume that the relatively high \( Challenge \) and relatively low \( Fantasy \) reduce the rate of change of educational effectiveness with respect to time respectively. So, \( b \) and \( a \) are denoted as \( Challenge \) and \( Fantasy \) respectively. Note that the inflection point, \( \left( \frac{1}{2a} \ln \frac{c}{d} + k \right) \), of the equation (2) needs to be positive. So that the following condition, \( c > \frac{b}{a} \), is obtained. The condition, \( c > \frac{b}{a} \), states that the constant, \( c \), is relatively higher than the constant, \( b \), to keep accelerating the educational effectiveness. Since the constant, \( b \), is \( Challenge \), the assumption of the constant, \( c \), as \( Curiosity \) is understandable.

To consolidate the idea of the coefficients, \( a, b, c, d, \) and \( k \), the relationship between \( x(t) \) and \( ETW \) should be considered. To take the advantage of the educational effectiveness through the Gamification needs to satisfy the area of \( ETW \) from \( t=0 \) to \( t=t^* \) must be less than the area of \( x(t) \) from \( t=0 \) to \( t=t^* \). Then the result given by

\[
ETW > \frac{2}{b} \left[ t^* + \frac{1}{2a} \ln \left( \frac{b+ce^{-dt-k}}{b+c} \right) \right]
\]

(4)

2 The reasonable values of the coefficients through example

If the amount of vocabulary words that can be learned through traditional methods of learning for 1 hour is 40 words, \( \xi = ETW \) \( t^* \), is 40 words. Where \( t^* = 1 \) and \( ETW = 40 \). Assume that the educational effectiveness through Gamification at \( t^* = 1 \) and \( k = 0 \) will converge to 80% of stable fixed point, \( \frac{2}{b} \), so that from equation (2), \( ce^{-d} = \frac{e}{4} \)
With the condition above, the equation (4), at $t = 1$, gives $40 < \frac{c}{b} \left[ 1 + \frac{1}{d} \ln \left( \frac{5b}{4c(b+c)} \right) \right]$. Assume that the initial point, $x(0) = \frac{a}{b} + c$ is 20% of the stable fixed point, $\frac{a}{b} + c$, so that $\frac{a}{b} + c = 0.2 \cdot \frac{a}{b} + c$ then $c = 4b$. Substituting the result into equation (4), then $40 < \frac{a}{b} \left( 1 - \frac{13.8683}{d} \right)$, so that $d > 1.3863$ and from the relationship above the value of $d = 2.7726$. Also we have $b < \frac{a}{90}$. The final assumption is that the initial point, $x(0) = \frac{a}{b} + c$, the initial point can be defined as $x(0) = \frac{a}{b} + c$. Since the result, $b < \frac{a}{90}$ states at least is 40% of the $E_{TW}$ has reasonable value as the initial point. So assume 50% $E_{TW}$ is initial condition, $\frac{a}{5b} = 2c$ Hence $a = 10b$.

**Conclusion from the example**

From the example above $d = 2.7726$, $a = 100b$, $c = 4b$ and $a = 25c$. The value of fantasy is much higher than the value of challenge and the value of curiosity is 4 times higher than challenge. Using the relationship of the coefficients, the inflection point, $\left( \frac{\frac{1}{d} \ln \frac{c}{b} + k \cdot \frac{c}{20} }{\frac{a}{b} + c} \right)$ is $(0.5, 50)$. The simulation of the example is presented in Fig1 below. To find the intersection of $E_{TW}$ and equation (2), set $40 = \frac{10}{0.1 + 0.4d - 2.7726}$, and the intersection point given by $(0.3538, 40)$.

Fig1: To satisfy the conditions in the example, set $a=10$, $b=0.1$, $c=0.4$, and $d=2.7726$.

All the coefficients satisfy the condition in example above. The example states that the ratio of fantasy to challenge is 100 which is 25 times higher than the ratio of curiosity to challenge. Note that the ratio is the relationship ratio between two factors, not the priority of the factors. In other words, the ratio of fantasy to challenge being 100 does not mean that fantasy is 100 times more important than challenge. As mentioned above, the absolute meaning of the values for the coefficients can be defined through additional research. The phenomenon of the simulation shows us that at the beginning, educational effectiveness through Gamification is just 50% of the traditional way but after reaching a tipping point at $t=0.3538$, Gamification effectiveness actually exceeds the traditional method.
3 Conclusion and Future Work

When the four primary factors have profitable the educational effectiveness through Gamification can easily exceed the educational effectiveness using the traditional way, $E_{TW}$. According to the example the result shows that at the beginning, educational effectiveness through Gamification is just half of the traditional way but the total amount of vocabulary words that can be learned through Gamification during 1 hour is 25% better than the traditional way.

In this research, only the sensitivity of ages and genders is considered for the first step. In upcoming work, we will systematize the dynamical model through substantive verification and we will focus on reconsolidating the dynamical model for the theoretical foundation of Gamification that can positively affect aspects of society including but not limited to Health, Environment, and Government.

Reference