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Beyond The Engineering Pedagogy: Engineering The Pedagogy, The Game of Experiential Learning

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Abstract: Modern constructivist pedagogical research emphasizes developing student-centred educational practices. This requires students to do extra effort and they should be equipped with the motivation to conduct such extra work load. However, the situation is dilemmatic since many students (in particular, undergraduates) tend to do their studies with the minimum effort needed to reach their goals. In this paper we analyse this dilemma from the game theory perspective, where we try to find conditions where students are willing to voluntarily take extra course work. We model the strategic interaction between the student and the teacher by a 2x2 non cooperative game. We suggest a mechanism for transferring the game equilibrium into the desired one, i.e. experiential learning equilibrium. We also show an experiment for identifying the energy needed to shift the equilibrium towards the desired one. The paper presents one of the very few game theoretical models that were developed in pedagogical research.

Introduction

Game Theory is a branch of applied mathematics that studies strategic interactions among agents. In strategic games, agents (players) choose strategies which will maximize their return, given the strategies the other agents choose. The essential feature is that it provides a formal modelling approach to social situations in which decision makers interact with other agents. John von Neumann’s book from the mid 1940’s on game theory is considered one of the firm establishing bases of this branch of science (Neumann et al 2007). One of the key figures in game theory is the Nobel laureate John Nash, well known for his works on non-cooperative games (Nash 1951). The non-cooperative game implies no binding on the players to commit for cooperation, the cooperation can be only self-enforcing (Nash 1951). Game theory models the strategic interactions among players in a context called normally a game. Each player in the game tries to maximize his/her gain out of the game. Many games, especially the prisoner's dilemma (Anatol et al 1965), are used to illustrate ideas in political science and ethics (Gates et al 1997). Game theory has recently drawn attention from computer scientists because of its use in artificial intelligence and cybernetics (Stirling 2003; Hill et al 2005), it has a very well established applications in economics and business (Perloff 2006). Game theory has an instrument called mechanism design (Gallien 2002) that aids in designing situations where all players would tend to choose a rest point, or equilibrium (desired by the designer of the game mechanism) that they will not deviate from because none of them will obtain extra payoff in case of choosing another state. This rest point is called The Nash Equilibrium in the literature (Nash 1951). Although the fact that game theory has been successfully applied to many social sciences such as economics and political science, we have noticed that pedagogical research has seldom utilized game theory as quantitative tool for analyzing and designing effective pedagogical practices. In this paper, we try to introduce a game theoretical model for modelling the strategic interaction between teacher and students. We use a simple mechanism design technique to transfer the game equilibrium into the one that fosters constructivist experiential learning.
Game Theory Model For Fostering Experiential Learning

Constructivist pedagogy is a very suitable framework for engineering education, since constructivism emphasizes the importance of experience and the student’s centrality in the learning process. Constructivism implies that engineering students should commence more experiential work alongside the university curricula, they should work on real or quasi-real projects, they should show autonomy and proceed with minimal contribution of their supervisors. This could be demonstrated as a greater challenge to the current students who were used on conventional ways of teaching and learning. There is the possibility that students might drop-out of higher educational institutes who take the reform step towards constructivism and experiential learning, and they will transfer to other institutes that are still maintaining the classical model of teaching and learning. Student drop-out from a university in UK will leave considerable negative impact on the institution since tuition fees form a large portion of the university income. Thus we see student tuition fees as a control parameter.

On the other hand, the reform of higher education into constructivist pedagogy is a strong necessity to cope with the required skills of modern engineers. This demonstrates a dilemma that we try to analyse and suggest a solution from the game theory perspective. Here we are using game theory to approach modelling students interaction with the teacher to develop a model that describes the current classical form of teaching and learning and use one parameter of this model—the student’s payoff- to control the equilibrium and move it to the desired one. We will call this game, the Experiential Learning Game (ELG). Figure 1 shows the representation of the ELG, also described as the strategic representation in the literature (Gates et al 1997). The ELG consists of two players, Player 1 is the student, and Player 2 is the teacher. Each player has two choices of playing resulting in four different possibilities. The student has two preferences on learning, the average learning effort way (AL), i.e. the classical learning way, or to learn in experiential learning approach which requires performing extra learning effort (EL) since experiential learning requires more involvement of the student into modern ways of learning such project based learning PBL, inquiry based learning IBL, and social learning. The teacher has two preferences for teaching, the first is with normal teaching effort (NT) which means here that the teacher spends average time on teaching, while the second is with over teaching effort (OT) where teachers spends more time and effort on teaching. The over teaching situation represents institutions with strong teacher-centered approach of teaching. This classification will yield four discrete states in the model:

- **State 1:** (AL,NT) refers to situations where the students effort on learning is average, and the teachers are teaching with the normal teaching effort. We will refer to this state with \( q_1 \).
- **State 2:** (AL,OT), here the students effort on learning is average while teachers are putting extra effort on teaching, we will refer to this state with \( q_2 \).
- **State 3:** (EL,NT), here the students are learning in experiential learning methodologies which requires extra effort, while the teachers are teaching with normal effort. We will refer to this state with \( q_3 \).
- **State 4:** (EL,ET), here the students are learning in experiential learning methodologies which requires extra effort, the teachers are putting extra effort on teaching. We will refer to this state with \( q_4 \).
In game theory each player receives different payoffs at the different states, these payoffs represent the utilities each party of the game would gain for the corresponding state. The students payoffs in the states $q_1, q_2, q_3, q_4$ are $a, b, c, d$ respectively, while the teacher payoffs are $e, f, g, h$ respectively.

In discussion with many educators and through our own experience we can say that most higher education institutes (excluding top ranked ones that attract highly motivated applicants), students in general have little aptitude to do extra learning effort, especially undergraduate students. Most teachers also tend not to allocate much more time for teaching, such as more material preparation, further office hours, aiding students more, etc, because this will deviate them from their research agenda. Historically, they are mainly assessed on their research outcomes in their academic career. To further advance modelling and analysing the strategic interaction between the two players, we will define the following set of implications (A):

- $b > a$, because in $(AL,OT)$ the student will receive extra teaching than it is the case in $(AL,NT)$, hence he/she gains more.
- $f < e$, because in $OT$, teacher have to do extra effort, hence gaining less.
- $c < a$, because the student have to do extra effort on learning when choosing $EL$.
- $d > c$, because the student will receive extra teaching in $(EL,OT)$ than it is the case in $(EL,NT)$.
- $b > d$, because the student in $(AL, NT)$ have to do less effort than it is the case for $(EL, OT)$.

A Numeric example with the previous constraints is shown in Figure 2. In this example one can observe that if the teacher chooses to teach in normal effort, i.e. $NT$, the student would not choose to learn with more effort $EL$ because he or she would consume more utilities that reduces his payoff from “10” in $AL$ to “5” in $EL$. The same reasoning applies when the teachers chooses $OT$, because $11 > 6$, so the student will mainly choose $AL$ whatever the teacher choice, this is called dominant strategy for the student. The other important observation is that the teacher will mainly choose $NT$ instead of $OT$, because in either case $9 > 5$, and $11 > 6$, so the teacher has also a dominant strategy that is to mainly play $NT$. We will proceed by analyzing the ELG game to show how the teaching and learning practice in many higher education institutes would rest at the equilibrium $(AL, NT)$. We will show how we can further improve the process from game theory perspectives. Lets assume that both players are playing with the following mixed strategies:

- Player 1 is playing $EL$ with probability $\alpha$.
- Player 2 is playing $OT$ with probability $\beta$.

To obtain the Nash Equilibrium we will analyze the players responses. Player 1 response to Player 2 ($R(\cdot)$) is given as follow:

$$R(\cdot) = \begin{cases} 
0 & \text{when } \beta = 0 \\
0 & \text{when } \beta \in (0,1) \\
0 & \text{when } \beta = 1
\end{cases} \quad (1)$$

The Player 2 response to Player 1 ($R(\cdot)$) is given as follows:
We can conclude that, given the set of implications (A), there will be one Nash equilibrium, which is (AL, NT), this is an asymptotic stable equilibrium. The state (AL, NT) means that students follow the average learning effort, and lecturers are following the normal teaching effort. This is probably the dominating state in most classical higher educational institutes. The Nash Equilibrium state (AL, NT) is describing this situation as shown in Figure 3. Fostering constructivism in engineering education implies moving the Nash equilibrium in the experiential learning game described above to the (EL, NT) state. To implement this, we will use the student’s payoff in the EL state as a control parameter. For a student to accept doing extra effort during the study curricula, he or she should get a convincing motivation or reward. This implies that the payoff in the student’s (EL, NT) state should exceed the payoff in the student’s (AL, NT) state:

\[ c > a \quad (3) \]

Let’s analyse the players responses when the inequality (3) holds. The Player 1 response to Player 2 in pure strategy replies will be given as follows:

\[ R_1(\alpha) = \begin{cases} 0 & \text{when } \alpha = 0 \\ 0 & \text{when } \alpha \in (0,1) \\ 0 & \text{when } \alpha = 1 \end{cases} \quad (2) \]

The Player 2 response to Player 1 in pure strategy replies will be given as follows:

\[ R_2(\beta) = \begin{cases} 0 & \text{when } \beta = 0 \\ 0 & \text{when } \beta = 1 \end{cases} \quad (5) \]

To obtain the responses in a mixed strategy game, we derive the expected payoffs. The expected payoff of Player 1 when choosing the AL is given as follows:

\[ E_1(AL) = a \times (1 - \beta) + b \times \beta \quad (6) \]

The expected payoff of Player 1 when choosing EL is given as follows:

\[ E_1(EL) = c \times (1 - \beta) + d \times \beta \quad (7) \]

For Player 1 to choose the EL rather the AL, he should expect to get higher payoff in the case of adopting the EL methodologies, hence the following condition should apply:

\[ E_1(EL) > E_1(AL) \quad (8) \]

\[ \Rightarrow c \times (1 - \beta) + d \times \beta > a \times (1 - \beta) + b \times \beta \]

\[ \Rightarrow \beta < \frac{c - a}{c - a + b - d} \quad (9) \]

Player 2 has a dominant strategy, he will reply with NT whatever the Player 1 is playing (constrained to the probability \((1 - \beta)\)). The players responses in the mixed strategies form will be given as follows:

\[ \begin{array}{c|c}
\text{Player 1} & \text{EL} & \text{AL} \\
\hline
\text{Player 2} & (0,1) & (1,0) \\
\end{array} \]

\[ \text{Nash Equilibrium (0,0)} \]

\[ \text{Figure 3: Dominant Nash Equilibrium} \]
The plot of mixed strategies responses given by (10) and (11) in 2D space to show the new equilibrium point is shown in Figure 3. The Nash equilibrium (1,0) represents the third state (EL,NT). One can infer from the previous analysis that the experiential learning can be fostered if the students were offered enough utility to compensate the estimated extra effort they have to put on learning when adopting constructivist practices.

The ELG model reveals an interesting character which seems to us rational. From the analysis showed so far, one can infer that students need higher payoff “c” to choose EL in case of institutions that have more teacher-centered approach in teaching, i.e. the value of \( \beta \) is higher. This is not a surprise because in such institutions, students are more dependents on teachers and they are less willing to take extra course work.

### Empirical Pedagogical Experiment

To verify the corresponding set of payoffs “c” and the related probabilities \( \alpha \)'s of the ELG model, we conducted a small system identification experiment on MSc students in the Chemical Engineering Department at Loughborough University, UK. The experiment aimed to verify whether increasing the students payoff would lead them to voluntarily choose the experiential learning approach. Also we wanted to get some indication of such payoffs. We asked the students the following question: If we offer you additional more complex course work (optional), that needs equivalent or more working hours to the whole set of four coursework that was asked from you for this Module, are you willing to take it? (Once it is taken, it should be finished. Such a project will involve the following elements:

<table>
<thead>
<tr>
<th>Payoffs</th>
<th>Number of Respondents</th>
<th>Means / Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra 2.5 points</td>
<td>8</td>
<td>2.13 / 0.355</td>
</tr>
<tr>
<td>Extra 5 points</td>
<td>8</td>
<td>2.50 / 0.417</td>
</tr>
<tr>
<td>Extra 10 points</td>
<td>9</td>
<td>3.00 / 0.500</td>
</tr>
<tr>
<td>Extra 25 points</td>
<td>8</td>
<td>3.63 / 0.605</td>
</tr>
<tr>
<td>Extra 50 points</td>
<td>9</td>
<td>5.67 / 0.945</td>
</tr>
<tr>
<td>Award of 5£</td>
<td>8</td>
<td>2.13 / 0.355</td>
</tr>
<tr>
<td>Award of 10£</td>
<td>8</td>
<td>2.58 / 0.397</td>
</tr>
<tr>
<td>Award of 25£</td>
<td>8</td>
<td>2.63 / 0.438</td>
</tr>
<tr>
<td>Award of 100£</td>
<td>8</td>
<td>3.88 / 0.647</td>
</tr>
<tr>
<td>Award of 250£</td>
<td>8</td>
<td>4.50 / 0.750</td>
</tr>
<tr>
<td>Free flight tickets to Paris</td>
<td>10</td>
<td>5.10 / 0.850</td>
</tr>
</tbody>
</table>

*Total number of the survued sample is 11*
literature review, mathematical modeling and theoretical development, complicated Matlab/Simulink models implementation, solving optimization problem, PID and MPC controller design, simulations, LabView DAQ, and real experimentation). Please indicate your answer for each of the following cases upon completion of the suggested project:

1= Not willing at all (0%), 2= Very little willing, 3= A little willing, 4= Probably will, 5= Quite willing, 6= Definitely (100%).

Then we listed a number of different payoffs and asked the student to select their willing degree of conducting the extra experiential learning project according to the previous scale. The students responses varied considerably depending on the payoff amount and nature. The listed responses and the corresponding probabilities in Table 1 reveals the correspondence of the ELG model to reality. The experiment gave us an identification of the control parameter of the model. However, further large scale, multidimensional (on the payoffs factor nature and amount) studies should take place to get expertise about the payoffs that can move students towards the desired equilibrium and yet still be economically feasible for the university.

Conclusion

Game theory provides us with analytical tools for modeling, analyzing, and probably controlling strategic social interactions among the involved agents, or a so called players. Many of us, the engineering academic members, are using game theory in our specific domain research such as artificial intelligent or control engineering. However, whether we love it or not!, we are involved in the pedagogical process mainly as lecturers. In this paper, we presented a case where we made use of game theory in the context of an educational process where we developed a 2x2 non-cooperative game for modeling the strategic interaction between teachers and students in case teachers wanted to foster experiential learning practices. We showed a small example of identifying the important parameters of the model, namely the control parameter, and the associated probability, such a model can be a base of more complex scenario in which one can utilize the first model implications.

References


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