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Using Game Theory in Computer Engineering Education through Case Study Methodology: Kodak vs. Polaroid in the Market for Instant Cameras*

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Our teaching proposal lies in explaining some of the core concepts of non-cooperative game theory by means of real cases of strategic decision within the computer engineering education. The innovative features of our methodology are based on the use of PC simulations to analyze the strategic decisions faced by Kodak and Polaroid under several circumstances. The discussion of the Kodak vs. Polaroid case fits very well to introduce the students the economic perspectives within the more technical discipline of engineering. With this new e-learning method, one the one hand, the students of computer engineering get a more realistic and complete vision in their learning and on the other reduce the degree of abstraction of the theory itself and thereby a greater motivation and interest in social sciences are achieved.

Keywords: game theory; non-cooperative games; Nash equilibrium; case study; engineering education

1. Introduction

The Economics discipline can be applied and adapted to several others; one of them is Computer Engineering. The study of economics and engineering have been related since the advances in computer technology have to be necessarily developed within a business and economic environment, particularly taking into account the competitors of the product or process created by the engineers.

Focusing on high education, these two disciplines can be put together through the study of game theory within the business field. In this sense, game theory is defined as the situation where each firm (player) tries to maximize its benefit, taking into account the decisions made by the rest of firms (players). In other words, game theory is a strategic management process where the decisions of the firms are dependent. For this reason, the relation and interaction among the firms in the market, how these decisions affect the market outcomes and therefore other firms are the kind of economic aspects that must be introduced in Computer Engineering bachelor.

In this paper, we use the Kodak and Polaroid real case to explain this strategic management process by means of the software Z-tree. Z-tree allows us to get simulations of the firms' behavior in the market under different circumstances. The computer engineering students can create these simulations by themselves, connecting both disciplines: economics and computer engineering.

This paper continues as follows. In section 2, we describe the Kodak vs. Polaroid case in the market for instant cameras. In sections 3, 4, 5 and 6 we analyze the central concepts of Nash equilibrium, sub-game perfect equilibrium and Bayesian equilibrium and we use them to explain Kodak and Polaroid decisions. In section 7, we present the simulation e-learning through Z-tree and the advantages of this methodology for the computer engineering students. Finally, in section 8 we summarize the main conclusions.

2. A real case: Kodak and Polaroid

On April 20, 1976 Kodak announced that the company would challenge the monopoly held by Polaroid for over 28 years in the market of instant photographic prints. The market for amateur photographic products was much focused and companies tried to maintain their sales figures secret, almost with the same intensity that they protected their trade secrets (Table 1).

Kodak had the largest market share in the industry, and although since 1967 it had been losing relative share in favor of other major companies (such as Ilford, 3M, Ciba, Turaphot, Fuji and others) still remained as uncontested sector leader. In 1975 the internal volume of retail sales in the U.S. for amateur photographic products was estimated around $6.6 billion, Kodak's sales were estimated at around 2.5 billion (37.8%), while information on Polaroid sales in the U.S. market were about $0.5 billion (7.5%). The size difference between the two companies was very important, without taking into account its capital structure. The operating accounts of both firms showed important differ-

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Table 1. Comparison of the Kodak and Polaroid consolidated accounts [1]

Consolidated accounts	Kodak	Polaroid
Net sales	4.959	813
Cost of goods sold	2.927	468
Advertising expenses	*no	52
R&D	313	64
Administrative expenses	632	121
Net profit	1.087	108

ences in the volume of gross profit where Kodak operations were ten times higher than the Polaroid ones.

Polaroid's business was based largely on their instantaneous, revealed cameras that while still enjoying legal protection in parts and collateral mechanisms, the main patent rights had recently expired. In April 1976 Polaroid was still run by its founder, Dr. Edwin H. Land, who remained CEO (Chief Executive Officer). Also Mr. Land had high-level of collaboration with William J. McCune, a Polaroid employee since 1939 who had worked very closely with Mr. Land in developing the system developer Lan instantaneous camera. In line with their attachment to the company and against the Kodak announcement, both chief executives claimed the superiority of their products and were willing to fight on all Kodak's instant development market fields, from the commercial to the legal, to defend exclusive rights still preserved on some parts and system mechanisms.

Kodak's top management in 1976 corresponded to two men of long tradition in the company, Walter A. Fallon, president and chief executive, and Colby H. Chandler, who was appointed executive vice president in early 1974. Both CEOs had been linked to the Division of Kodak photo and Canada United States which had carried out the massive program of instant cameras research led by Dr. Albert Seig.

3. Nash equilibrium in non-cooperative games

In human relationships the conflict arises as a strategic interaction between individuals. Faced with the traditional view that in all conflicts in order for one individual to win another must lose (lump-sum games), a game theory emerges as the study of human conflict in situations of mutual benefit, where participation in the game generates a higher value to the one that each player can guarantee for each of them individually.

The cooperation can generate a value, that is to say, a "pie" or social product. However, this does not mean absence of conflict, since there will be an intense struggle to stay with the largest share of the pie. That is, if everybody wins (win-win), this does not mean absence of conflict since some of the players might gain more than the others.

It was the unquestionable merit of John Nash to clearly formulate the concept of balance and also state the conditions for their existence. In sum, the breakthrough was finding a general solution concept for games of strategy (non-cooperative), surpassing the narrow framework of zero-sum games (strictly competitive) with its brutal conflict of interests. Von Neuman and Morgenstern (1944) developed an elaborate the theory of two-person game with sum, the so-called "games of strategy". But their treatment of the n-person game based on the analysis of the interrelationships of the various coalitions that the players could form was missed. This was the reason why Nash, labeled this approach as "cooperative" in the introduction of his 1951 article, and, by contrast, ("in contradistinction") he thought to base his theory in the absence of coalitions and the assumption that the players should act independently without co-operation or communication with any of them ("non-cooperative games").

In fact, as he himself tells us, the basic ingredient of the theory of Nash, was the notion of an equilibrium point that generalized the concept of solution for zero-sum games of two players. Nash defined the equilibrium as optimal responses to each player for each of the remaining choices (pairs of good strategies, one against the other, in the case of two sets of zero-sum) and demonstrated the existence of at least one equilibrium in mixed strategies (probability distributions on the sets of pure strategies) for finite games (games with n players, a finite set of pure strategies and a payoff function that provides a real number for each of the combinations of n pure strategies selected by the players).

In sum, the breakthrough was finding a general solution concept for games of strategy (non-cooperative), surpassing the narrow framework of zero-sum games (strictly competitive) with its brutal conflict of interests. A rational player will try to foresee the actions of others and in terms of these will choose the most convenient, but then, since he knows that the other player is also rational, he will "get into their shoes" and infers that, as the rival equally reasons, he will elect, in turn, the new action that is the most profitable and, since he foresees the new response of the opponent, once again he will elect his best response.

There may be points of convergence (equilibrium), where this mutual subtle process will stop forecasts since the selected strategies are both the best response of one against another. It was the great merit of John Nash in the early 50's to formulate the concept and the conditions of existence of this equilibrium. To explain the concept of Nash equilibrium we can use a good game called the "Chinchi-moni." We consider a simple form with two players, 1 and 2, who have two strategies or options to take a coin, heads, C, or tails, X. The payments are as follows: Player 1 loses the coin-delivered to 2—if the two coins match, both are head or both are tails, conversely, player 1 gets player 2's coin when coin does not match (heads or tails and tails or heads). Both players make their decision simultaneously.

Each one selects the position heads or tails of its coin without the other knowing. In this case the game starts with player 1 to choose between heads and tails (C, X), and then player 2 makes the same choice without knowing what player 1 has previously chosen. This is the reason why the two decision nodes of player 2 are included in the same set of information (the dashed line that joins or includes). In fact, since player 2 ignores the previous decision of player 1, he is unable to distinguish node and really only has one choice: heads or tails (C, X).

This is one reason why we selected this game for the beginning of our discussion. The information available for players is a key element of their decision. If player 2 had a secret available tool to observe the election of player 1, he would know what node he was, and the game would be trivial, the one who started the game, he would surely lose it. It is a type of game where one player must make the same choice in several different nodes without sufficient information. This extensive way was not initially used by Nash. Nash used the strategic form of the game, but for expository reasons it is more convenient to start with the model of the game in extensive form (the extensive form was due to Kuhn, who made an important equivalence theorem for games with perfect memory.

The game (in extensive form) is represented by the set of players (1 and 2), an order of events which is represented by a tree with nodes and segments (segments arrows indicate the precedence relation on the set of nodes), the order of movements of the players (assigning initial and intermediate nodes to them), the actions that each player can make at each node (whose cardinal is equal to the subsequent nodes in the tree), the sets of information (encompassing those nodes that the player is unable to distinguish because they lack sufficient information for it) and payments of the players in every possible move, that is, end node or complete story).

4. A game theory model

For our case the strategic decision on the entry or not to entry in the market for Kodak crucially depends on the assessment made of the possible responses of Polaroid [2]. But none of the executives of Kodak knows what utilities and valuations Polaroid executives are searching for. The essence of competitor analysis tells us that they are strongly committed with the idea and the product of the company, but of course their fundamental goal is the company's profitability and maintaining the value of their stocks, without which they could not survive. Similarly, the strong commitment of Kodak executives with the development of Kodak's new machine must do an operation expected to enter the market, but its main objectives were also to maintain the profitability of the company so that the fight Kodak-Polaroid in the market cannot be interpreted as a 'death struggle' since Kodak cannot 'burn their ships' [3].

However, the responsiveness of Polaroid is very important as long as its action against Kodak can succeed in ridding it out the market. In this situation the game changes completely and the analysis with the previous scheme would be completely wrong. Kodak is only interested in landing on Polaroid market, perhaps even ending up letting it out of the market, provided that it will report an adequate return. If the cost of the 'landing operation' is very high and, due to a large commercial and legal struggle, the expected profitability is reduced, a company even the most powerful, must withdraw from this market segment and focus on those others which underlie profitability. Therefore, it is not logical to assume that it produces no other effects than those of reducing their benefits. If Polaroid gets Kodak waive its program of expansion in the instant development segment, the determined Lan fight against the Kodak landing would have the highly expected returns to recover the monopoly in the segment of instant cameras.

With this discussion, we can still get some analysis of interest with a game theory model. Consider the following game, which represents the tree of Kodak and Polaroid strategies (Fig. 1).

The game begins with Kodak's decision to enter or not to enter in the instant camera market monopolized by Polaroid. If Kodak does not enter, its payments are zero and Polaroid enjoys an undisputed high yields monopoly, which is assigned a payment of 3. If Kodak decides to enter, the important thing is the reaction of Polaroid. Its two strategies are: 1) an accommodate input (share) or 2) fight against Kodak with dissuasion at the entrance.

By contrast, the weak Polaroid has a low probability of driving the market to Kodak. In this case two situations can be considered for a Polaroid strong or weak. The strong Polaroid can expel Kodak out of the market and regain its monopoly with a high probability. In this case the payments of its strategy to combat the entry of Kodak would be

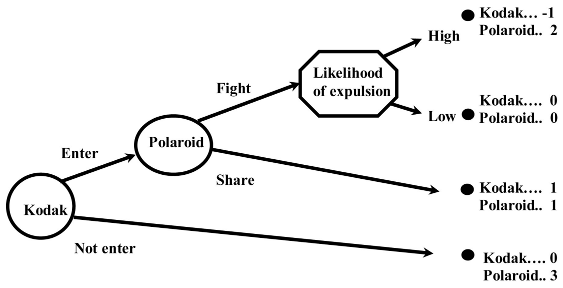

Fig. 1. Kodak and Polaroid: a perfect information game.

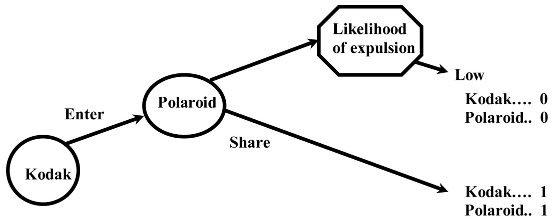

Fig. 2. The game of weak Polaroid: Kodak Enters—Polaroid Shares.

2, since it would regain its monopoly in the instant camera market and payments will be lower than struggling to accommodate the input and sharing the market with Kodak.

5. Analysis with complete information

To analyze the game it can be divided into two subsets of complete information: one for the weak Polaroid case (low probability of ejection) and one for the Polaroid strong (high probability to expel Kodak). The game of weak Polaroid is shown in the following Fig. 2. There are two Nash equilibriums or pairs of strategies, which are mutually the best response to each other. However, the balance of the game that Kodak does not enter because they are afraid that Polaroid fights (in which case you lose 1) is not logical. It is based on an incredible threat. Once Kodak has entered, the equilibrium in the subset, in which Polaroid chooses whether to fight or share, is sharing. It's the strategy which gives the highest payment (1). The threat to fight to deter the entry of Kodak is contrary to its interests, as it provides a lower payment (0).

Selten (1975) showed that Nash equilibrium can be refined to eliminate logical problems of incredible threats. In games of perfect information the concept of "perfect equilibrium subset" can be applied. That is, the strategies of the players have to be their best answers both in the complete game, as in every one of its possible subsets. The equilibrium, in which

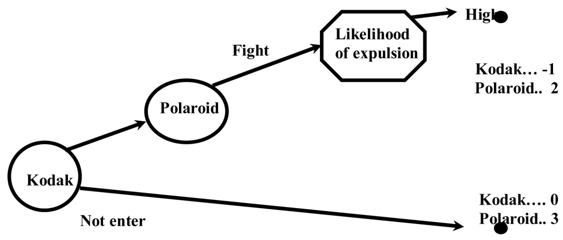

Fig. 3. The Game of Strong Polaroid: Fight, not Enter

Kodak does not enter because it is afraid that Polaroid (weak) fights, is not perfect in subsets.

The only perfect equilibrium in subsets of weak Polaroid's game is: Polaroid enters and shares. An easy way to get perfect equilibrium is to use the technique of retrospective induction. That is, look forward, and situates you at the end of the game, and make decisions backwards, choosing the equilibrium strategies of the players in the different subsets.

The other game of complete information is the strong Polaroid. Its decision tree and its payments are shown in Fig. 3.

The situation now is the opposite to the previous game of a weak Polaroid. The probability of inducing Kodak to abandon the market for instant cameras is considered high by the strong Polaroid.

If we now apply the retrospect induction [4], we can see that if the likelihood to expel Kodak instant development from market is high, Kodak loses (–1), but Polaroid gets an important return from medium to long-term to retrieve their monopoly in the market –which is represented with a payment of 2. Consequently, whether that probability is estimated as high, Polaroid should fight, since the recovery of monopoly to the abandonment of Kodak gives a payment greater than accommodation of entry, resigning them both to share the market (1).

In the subset following Kodak's entry the Polaroid's best replay is fighting. This strategy gives them the greatest payoff (2), since they recover their monopoly position in the market after reducing prices and mark-ups. In this case, Polaroid would never share and Kodak's best response now is not to enter. The only perfect equilibrium in subset is: (Do not enter, Fight) (Fig. 3).

When we analyze weak and strong Polaroid games with complete information models clear conclusions are obtained. The strong Polaroid always fights and the weak Polaroid always shares. However, the analysis is incorrect. The reason is that the probability of expulsion hides a strategic game with conflicting incentives. Polaroid's interest is to make Kodak believe that it is strong and is determined to fight, so that Kodak does not enter. In contrast to Kodak, Polaroid's interest is to make Kodak believe that it is much stronger, that is to say, that Polaroid is weak compared to Kodak so it must share. What is the correct way to analyze this conflict of interest on the types or characteristics of the players and their payments?

6. A Bayesian equilibrium

In the previous game the information is incomplete because we do not know the payoff function of Polaroid. How to analyze a game with two possible types or payments without losing substantial information on the strategic interaction of the players on those types? The solution (due to Hersanyi, 1968) is to introduce an additional player, 'chance'. "Chance" decides on strong or weak type of Polaroid base on 'a prior' probabilities or convictions of Kodak. The game becomes a game of complete information that can be analyzed with Bayesian methods. 'Chance' decides the type of Polaroid, based on 'a priori' beliefs (convictions) or probabilities of Kodak. However, only Polaroid knows its type. Kodak can only observe the reaction of Polaroid in the market: to share or fight. Thus, we have a game of imperfect information, where the weak Polaroid knows that Kodak does not know what it is. This gives an informational advantage and provides an opportunity to 'camouflage' as heavy fighting. Polaroid weak type has an incentive to fight.

In the previous analysis, we did not study the fundamental question of the strategic interaction between both companies in order to estimate the probability of inducing the withdrawal of Kodak through the struggle of Polaroid [5]. Polaroid's interest is to convince Kodak that this probability is high and converse, Kodak's one is to induce Polaroid to revise downwards their assessments. In fact, the actions and reactions of both tend to guide inferences, anticipations and a posteriori reviews of their likelihood assessments. This arises as an extraordinarily complex interaction, where there are strong incentives to disorient the opponent feigning (pretending) strength which is not available [6].

We can consider that both the commitment and interest of Kodak are known by both players, but Kodak is the only one with uncertainty about the real type (weak or strong) of its opponent (Fig. 4). Polaroid has enough confidence in their ability to cope with Kodak and force it to leave the market and assigns a high value to its payment, in the case of fight, (2), or conversely, it has little confidence in their ability to struggle and resist assigning a reduced payment to its strategy of struggle (0). However the weak Polaroid is aware that Kodak does not really know what type it is and may take advantage of this situation.

Actually we do not know the payoff function of Polaroid. Kodak knows that there are two possibilities: a) Polaroid is *strong*, in which case they will fight, b) Polaroid is *weak*, in which case, after the initial reactions, eventually, they will end up sharing the market.

We have incomplete information and little can be said about the game. Although today it is apparently very simple, Harsanyi's idea [7] was really great. He was able to complete the information of the game by introducing "nature" as a random player who chooses the type of Polaroid and then reveals their own type. The game becomes a game of imperfect information where Polaroid know its type and Kodak knows the probable distribution that operates by chance, so that Kodak is able to review its a priori likelihood assessment of the Polaroid's type by observing Polaroid actions in the market [8].

Using a simple form, the game begins with nature choosing Polaroid type, either strong or weak, with probability θ or (1-θ) respectively. The incoming Kodak does not have information to evaluate the type of Polaroid beyond the initial distribution of probabilities, for this, the two Kodak nodes fall into the same set of information (the oval dashed) and really it only has a choice to enter or not to enter. Polaroid knows its type since in each of the corresponding game tree branches has the payments corresponding to its type in case of fight (2 when it is strong and 0 when it is weak).

In this simple way strategic interactions fall outside the game, but now we are ready to consider them introducing the following periods of the game. If Kodak decides not to enter, a node is reached in the endgame. Similarly, if Polaroid shares, we also put a 'black point' in the endgame, and Bayesian reviewing allows Kodak to infer that Polaroid is weak (because strong Polaroid never shares). But if Polaroid decides to fight, a new round of the game is initiated, where Kodak must decide whether to

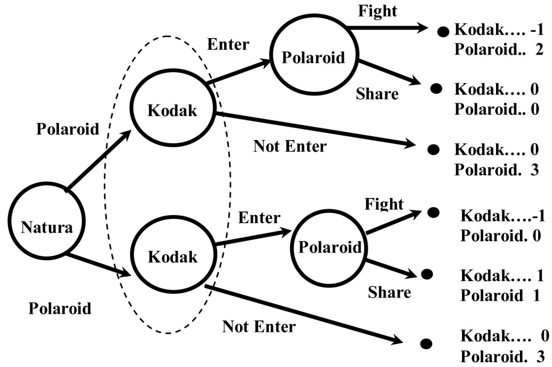

Fig. 4. Kodak and Polaroid as an imperfect information game.

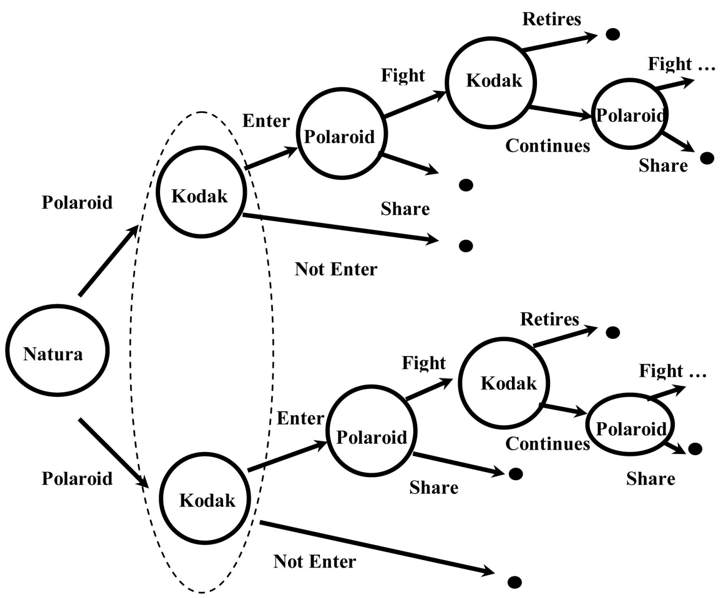

Fig. 5. Kodak and Polaroid: strategic interactions.

withdraw or continue in the market for instant cameras[1].

The most interesting thing is that now we can see that the weak type of Polaroid may want to fight in the first moves. Indeed, Kodak will update their perceptions of the likelihood of both types of Polaroid, strong or weak, according to Polaroid's behavior. If weak Polaroid decides to share, it discovers its type, as the strong will continue to fight. The established monopoly also has a disadvantage in case of fighting, at first, it is the one who has the largest market share and holds the stakes with low income prices which represent(representing) a significant burden. However, if the weak type can sustain the fight for several periods, it can succeed because opportunities are on its side. The entrant also knows it but, if the fight is prolonged, it can cause withdrawal by the excessive cost of the operation.

7. Game theory, real cases and e-learning

In this section, we propose a way of implementing this real case using e-learning in order to facilitate an easy assimilation of game theory by the students. This real case based on game theory can be friendly introduced to the students by means of the new tools existing in the e-learning environment. For our case of study we can use the advanced presentations that platforms offers in the web [9]. Fixed presentations are an insufficient tool to understand the theory of Microeconomics. The nature of these courses (changes in graphics, in conditions of the initial hypothesis, etc) make necessary to adapt the needs of our subject with advanced tools like movies, interactive videos or flash animations by means of dynamic simulations of Microeconomics exercises [10]. That is a way to use the animations to prepare problem-based homework activities [11].

In practice, these games require to be solved using complex mathematical operations. A friendly method to obtain the same results is by means of graphical schemes [12]. In our case, we have used the simulating software Z-Tree. This specific tool allows us to create simulations of the different possible situations within our real case: Kodak vs. Polaroid. One of the advantages of using Z-tree is that it can be used with this purpose, using matrices and decisions trees to easily understand the reasoning behind the final results. The solutions are obtained directly from the different determinants which lead to one point or another through the strategic interaction process between Kodak and Polaroid.

To undertake this technical methodology, we need to divide the whole game into subgroups, one for each different situation: perfect information game and imperfect information game and, within this different type of games we have additionally to perform the game of "a weak" Polaroid and the game of "a strong" Polaroid. If any initial condition changes, the results will change automatically. With this tool, the students can understand the strategic interaction between both firms in an easier way under all the possible scenarios. Therefore their

[1] In the game described below, we ignore the payments specified in the different endgame situations that are marked with black spots.

motivation to the economics discipline in particular and to social sciences in general can be increased since we are explaining this real case by resorting to the game theory discipline and by using specific PC software in conjunction with the specialized knowledge in simulation software Computer engineering students have.

The creation of this tool jointly with an interactive environment helps teachers fully express their didactical ideas, finalize the educational approaches and methods to be adopted [13] and increase the comprehension and motivation in students.

8. Conclusions

This paper analyzes the real case of Kodak's entry in the market for instant cameras previously monopolized by Polaroid resorting to the game theory discipline. In this kind of games, the behavior of one company can determine different solutions depending on the expected behavior of the other company and vice versa. This social vision into this type of real case analysis will help computer engineering students to give a greater importance to social sciences in their bachelor, aside from their more pure technical learning.

With this learning method, they are aware that when a company decides to maximize their benefits, the introduction in the analysis of the potential strategies of competitors can lead to stable solutions different to the Pareto optimum, only due to the strategic management in the market. For this reason, they achieve a complete learning, not only based on the study of informatics but also with a global perspective to incorporate considerations in the field of economics and business at the time of implementing their projects or jobs.

This study is carried out through the simulation software Z-tree. With this e-learning methodology, computer engineering students can configure by themselves the possible situations of this game using simulations. Once they create the case with this software, they obtain automatically the possible results under the different situations.

The main advantages of using this e-learning proposal, including real cases, is to reduce the degree of abstraction of the theory itself and, thereby, to achieve greater student motivation once they are be able to build the entire game, using their knowledge in computation.

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