Game theory and strategy in medical training

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OBJECTIVE This paper analyses how game theory can provide a framework for understanding the strategic decision-making that occurs in everyday scenarios in medical training and practice, and ultimately serves as a tool for improving the work environment and patient care. Game theory has been applied to a variety of fields outside of its native economics, but has not been thoroughly studied in the context of health care provision.

METHODS The paper discusses four of the most common 'games' and applies each to a scenario in medicine to provide new insight on the incentives and drivers for certain types of behaviour and a deeper understanding of why certain results are valued more strongly than others.

CONCLUSIONS Using game theory as an integrative tool, in conjunction with good judgement and a sound knowledge base, trainees and physicians can work to better recognise where competing priorities exist, understand the motivations and interactions of the various players, and learn to adjust their approaches in order to 'change the game' when their preferred outcome is not the most likely one.

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WHAT IS GAME THEORY AND HOW IS IT USED?

Game theory is a mathematically-based conceptual framework (originally developed for economics) for predicting, describing and explaining behaviour in strategic situations, specifically those in which another person's decision-making will directly affect the outcome. In game theory, models are applied to specific types of strategic conflict in the form of a 'game', or a simplified version of the interactive strategic decision-making process that allows prediction of outcomes. A game must have at least two interdependent, rational 'players', who pursue their own best interests and who make decisions based on their calculations of the other player's strategy. The players may make either simultaneous or sequential moves, and each player at the conclusion of the game receives a certain payoff, which could be in the form of money, influence or other items of value, depending on the game. The players, when entering the game, are aware of their own preferences as well as those of the other player.[1–5]

John von Neumann and Oscar Morgenstern's 1944 work *Theory of Games and Economic Behavior* originally discussed zero-sum games, which require one player to win and the other to lose for a net payoff of zero, and provided the framework for future elaborations on the concept. They demonstrated with their 'minimax theorem' that a finite, two-person, zero-sum game should end in an equilibrium where both players, in considering each possible move the other player could make, have pursued a strategy to minimise their own losses, which also reduces their potential maximum payoff.[6]

John Nash subsequently introduced the concept of cooperative and non-cooperative (or non-zero-sum) games. Additionally, he demonstrated that similar predicted equilibrium outcomes, which are now referred to as Nash equilibria, exist in non-cooperative games, and proposed the Nash bargaining solution for cooperative games. In non-zero-sum games, the incentives for each player to minimise his or her losses leads to a situation in which the two players do not cooperate, even though cooperation would produce the best possible outcome for both, and both players thus end up with a less-than-maximal result. Nash noted that any game that does not end in this result is almost certainly because at least one player is in need of education about how to more effectively pursue his own interests.[7–14]

Outside of its native economics, game theory has been applied to a variety of fields, ranging from international relations to sports strategy and dating. In international relations, the most recognisable examples relate to nuclear armament and deterrence strategy.[15,16] Sports analysts have also used game theory to determine when a particular game plan is most likely to work based on an opponent's likely strategy.[17] Several articles have also discussed how game theory can be used to model dating interactions, particularly how to respond more successfully to the other person's strategic 'moves'.[18–20]

Finally, it is important to note the distinction between game theory, which models strategic interactions, and gamification, which is the process of turning non-game activities into games. Gamification has gained popularity over the last several decades, but the application of a game-like structure to various activities is completely distinct from the strategic modelling framework game theory provides.

GAME THEORY AND MEDICAL EDUCATION

This section seeks to demonstrate how game theory models could be applied to real-world scenarios to help physicians, educators and students gain a new perspective on the motivations, strategies and complicating factors that can affect the outcomes in each case. To do so, we discuss four game theory models and present a conceptual discussion of their relevance to strategic interactions in four scenarios in medical education. The scenarios are not intended to be an exhaustive application of game theory to medical training; rather, they are intended to provide examples of how elements of game theory could be used to model outcomes. Game theory cannot give exact numeric or data-driven explanations of what will happen in reality, particularly because human behaviour is not always rational or purely self-interested, but it can provide insight into the dynamics that lead to a particular outcome. Although the scenarios we chose focus on a specific subset of medical education, game theory's frameworks for analysing strategic interactions could be applicable to a wide range of scenarios throughout undergraduate and postgraduate medical education. Additionally, the discussion will identify some of the factors that complicate each game and its results, and propose basic strategies to accommodate or encourage these as appropriate.

THE PRISONER'S DILEMMA

The Prisoner's Dilemma, one of the best-known models of a two-person non-zero-sum game, was proposed by Merrill Flood and Melvin Dresher and formalised by Albert Tucker in 1950.[21] Its name comes from the set-up of the scenario, in which two people, let us call them Adam and Barbara, are arrested and separated for interrogation. Each is given the same terms: if Adam confesses to the crime and Barbara does not, Adam will serve 1 year in prison and Barbara will serve 10 years in prison (and vice versa if Barbara confesses and Adam does not). If Adam and Barbara both confess, they will each serve 5 years in prison. If both stay silent, each will serve 2 years in prison (Fig. 1).

In this game, the conflict between individual interest and mutual benefit drives the game toward its Nash equilibrium, or the situation in which each player has chosen the most rational strategy for his or her interests and neither can do better by unilaterally changing that strategy. In this case, each player can minimise his losses, in the form of less jail time, by confessing, regardless of the strategy the other player pursues. For example, if Adam chooses to stay silent, he runs the risk of 10 years of jail time if Barbara confesses. Conversely, if Adam confesses and Barbara also confesses, Adam gets only 5 years, thereby minimising his losses, and, as a bonus, he could end up with only 2 years if Barbara decides to stay silent.

Because of the risk of serving significantly more jail time if the other player confesses, and because the players have no way of talking to each other before they make their decisions, the most mutually beneficial outcome (in which both stay silent and serve only one year) is unlikely to occur. As a result, the Nash equilibrium lies in both confessing. This scenario thus illustrates how, in a single-round Prisoner's Dilemma, cooperation is never a purely rational strategy.[22,23]

		Barbara	
		Stay silent	Confess
Adam	Stay silent	2,2	10,1
	Confess	1,10	**5,5**

Figure 1 Payoffs in the Prisoner's Dilemma. This chart details the relative payoffs for each potential outcome of the Prisoner's Dilemma, with the Nash equilibrium highlighted in the bottom right corner

THE PRISONER'S DILEMMA: MEDICAL STUDENTS' STUDY HABITS WHEN EVALUATED ON A CURVE

Several studies have indicated that medical students who are graded on a simple pass or fail system, as opposed to using three or more grading designations (i.e. honors, pass or fail) designed to allow more comparison between students' performances, have less anxiety and stress, feel less like they need to compete with their classmates, and are not significantly disadvantaged in their residency applications.[24–27] Although studies like these that measure well-being rely on inherently subjective data, this scenario can serve as an example of a case in medical education where non-cooperative activity is strongly encouraged. Consider students' study habits in an environment where the students are evaluated relative to their colleagues. In this scenario, each student has choices about how to approach studying: each could choose to self-study a little bit, allowing more time for collaborative work and study, or to self-study a lot to try to separate him or herself from the others.

This case functions as a Prisoner's Dilemma because the incentives are highest for each student to self-study a lot, with the most favorable individual outcomes occurring when one student self-studies a lot and the others self-study only a little. The most mutually beneficial outcome, both on an individual level and for the students' potential contributions to the practice of medicine as a whole, occurs when all students spend a reasonable amount of time self-studying. However, this is unlikely because each student has strong incentives to do more, either to get a boost over the others or to keep up in the event the others also decide to work much harder. This leads to an inefficient Nash equilibrium in which all of the students expend more resources to end up in the same position relative to each other, thereby failing to maximise their potential joint returns (Fig. 2).

The Prisoner's Dilemma can thus help us understand how the dynamics in this type of strategic

		Student 1	
		Study a little	Study a lot
Student 2	Study a little	3,3	1,5
	Study a lot	5,1	**2,2**

Figure 2 Grading on a curve as a Prisoner's Dilemma

interaction could lead to burnout: the incentives encourage all players to work harder for a very small appreciable gain in value, and do not allow them to maximise their potential payoff.[28] Although we used medical students for this example, the scenario is equally applicable to residents, who are often similarly incentivised to compete against each other in a system that evaluates them relative to each other.

This model can also help explain why students and residents may be reluctant to collaborate: instead of focusing on maximising their training, the incentive structure could drive them to try to outdo each other to obtain the highest individual payoff. The long-term competition among trainees could result in physicians viewing each other as competitors rather than members of a team working toward a common goal.

Escaping this Prisoner's Dilemma would require taking steps to increase the individual payoffs for teamwork, cooperation and collegiality among residents in an effort to turn the situation into a game with more attractive cooperative equilibria (such as the Stag Hunt, which is discussed in the next section).[29]

THE STAG HUNT/ASSURANCE GAME

Game theory can also be used to model scenarios with more incentives for cooperation, as in the Stag Hunt or Assurance Game. The foundation of this model was initially described by Jean-Jacques Rousseau in 1755;[30] in it Adam and Barbara are going on a hunt. They take up separate posts and both have the opportunity to choose to hunt either a stag or a hare. A stag would provide more than enough meat for both, but Adam and Barbara must both stay at their posts and cooperate to kill it. A hare, by contrast, would provide some meat for Adam and none for Barbara if Adam chooses to leave his post to catch it, and vice versa. If both leave their posts to catch the hare cooperatively, they will both end up with some meat, although less than if they had chosen to cooperate on the stag. The best possible outcome for both is to cooperate on hunting and killing the stag, which has the highest value, and the next best outcome is to cooperate on hunting and killing the hare. These are the two Nash equilibria for this game. The worst outcomes, therefore, involve scenarios in which one player attempts to cooperate and the other does not, leaving the one who wanted to cooperate with nothing and the defector with just some meat (Fig. 3).

		Barbara	
		Hunt stag	Hunt hare
Adam	Hunt stag	**3,3**	1,0
	Hunt hare	0,1	**2,2**

Figure 3 Payoffs in the Stag Hunt. This chart details the relative payoffs for each potential outcome of the Stag Hunt, with the Nash equilibria highlighted in the bottom right and top left corners

The Stag Hunt is risk-dominant because it requires players to trust each other and work together to achieve the best outcomes. The players' strategies are ultimately based on what they believe the other player will do, and whether this will result in an adequate payoff. This is a challenge because the players are always tempted to go after something for themselves (chase the hare) to ensure that they do not end up with nothing.

However, this game is much more likely to result in a mutually beneficial outcome than the Prisoner's Dilemma because there is less conflict between individual and mutual benefit. Adam and Barbara can always improve their individual result by working together, so both Nash equilibria involve cooperation.[4,31,32]

THE STAG HUNT: MOTIVATION TO TEACH AND LEARN IN THE ATTENDING–RESIDENT RELATIONSHIP

For a case in medical clinical education with more incentives for cooperation but an element of risk, consider the relationship between a resident and an attending physician and their respective motivations to teach and learn in the clinic as a Stag Hunt. The resident and the attending physician can each choose to do enough to fulfill their obligations, or they can choose to go above and beyond in their duties. This game has two cooperative equilibria, meaning that both players gain maximum utility by going above and beyond in their shared clinical duties, and will achieve the next best results in a scenario where both do enough to succeed. As such, there is an incentive for the attending physician and resident to cooperate on matching their motivation levels. However, each takes a risk in attempting to cooperate. If one chooses to commit extra time and the other does not, both still may receive some utility from the interaction, but one will be putting in significantly more effort for less return (Fig. 4).

		Attending	
		Enough to succeed	Overachieve
Resident	Enough to succeed	**3,3**	1,2
	Overachieve	2,1	**4,4**

Figure 4 Attending physician's and resident's motivation as a Stag Hunt

Although personal motivation to work hard is driven by a variety of factors, the Stag Hunt can help demonstrate that a lack of trust between the attending physician and resident should be strongly considered as a potential factor contributing to scenarios where the most mutually beneficial cooperative equilibrium is not reached. As in the previous scenario, this could easily be applied to the understanding between medical students and professors, each of whom may depend in some part on the other's motivation level to determine their own. For example, consider how a professor's motivations for creating a good lecture may fluctuate when medical student attendance is low, and conversely, how medical students' motivation to attend lectures when the presentations are not overachieving may change as well. This basic example serves as an illustration of one of many scenarios that define educational commitments and the types of incentives that may affect participants' motivation.

Skyrms describes this challenge in terms of a broader 'social contract' that is applicable to this type of risk-dominant scenario. In trying to adopt a new social contract, or set of norms, everyone in the society must participate. Therefore, all players have a decision to make about whether to devote energy to making a change, or to maintain the status quo. The first choice, which carries the greatest theoretical reward, also carries a high risk, whereas maintaining the status quo provides a lower payoff but almost no risk.[33] The major challenge in achieving the most beneficial cooperative equilibrium is thus how to convince the players that the payoff is worth the risk, and that changing their beliefs about what the other players will do is a wise strategy.

The personalities of the players thus play a large role in the outcome of a game like the Stag Hunt: those who are more risk-averse will require more convincing to reach the most mutually beneficial outcome, whereas those who do not mind the risk may have an easier time coming around to the better result. The relationship between the two players is also key, because even a player who does not mind risk may be unwilling to take a leap of faith with another player who seems untrustworthy, even though the relationship can only grow if trust is offered. The willingness to assess trustworthiness and offer a certain amount of trust may grow easier with age and experience, so a player's background can also play a key role in decision-making in this scenario.

THE ULTIMATUM GAME

The Ultimatum Game models a bargaining scenario in which players make sequential moves in a game with a certain number of rounds; it can be played with a single round or in multiple rounds with counteroffers. In this game, Adam and Barbara are given \$100. Adam is told to divide the money between the two players, and Barbara is told that she can either accept or reject Adam's offer. If Barbara accepts, they both walk away with the amount of money they were offered. If Barbara rejects the offer, neither receives anything (Fig. 5).

Adam can choose to make either a 'fair' offer, such as a 50–50 split, or an 'unfair' offer, such as a 99-1 split. Game theory indicates that Barbara, as a rational player, should accept any offer greater than zero, and she will potentially finish the game with more money than he had when he started, and could even accept an offer of zero because it costs her nothing. Adam, therefore, has a high incentive to offer an unfair split, which Barbara should have a high incentive to accept.[34,35]

THE ULTIMATUM GAME: ACADEMIC RESEARCHER NEGOTIATING SALARY INCREASE

The Ultimatum Game could be used to model a variety of single-round negotiation scenarios in medical

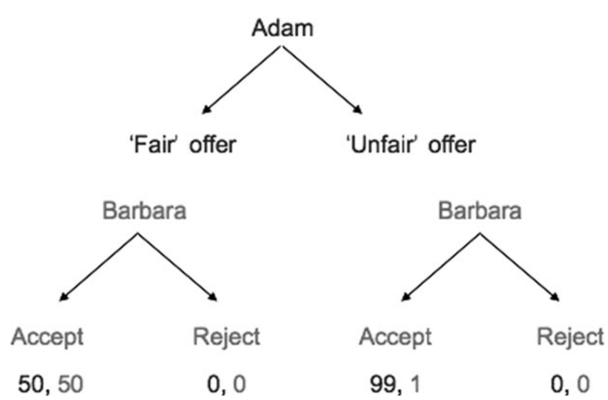

Figure 5 Payoffs in the Ultimatum Game. This chart details the relative payoffs for each potential outcome of the Ultimatum Game

training and practice whose results depend at least in part on the perception of fairness. As an example, consider an administrator who employs an academic researcher at a medical institution. This researcher has been part of the administrator's team for several years, and she has spent significant time and resources to train him. For his part, the researcher has been making advances in his field, and other institutions have begun to offer him larger salaries to leave his current job. Let us assume that the researcher would like to stay in his current job, but would like his compensation to be increased commensurate with the impact of his work. One afternoon, the researcher goes to the administrator and delivers an ultimatum: give me a raise or I am going to take another job. The researcher could demand a 'fair' or an 'unfair' raise, and the administrator must then decide whether to accept or reject it.

If the researcher demands a fair raise and the administrator accepts, he will keep his job and the administrator will keep her employee, albeit at a higher cost, leading to a slightly lower payoff for the administrator. If the researcher demands an unfair raise and the administrator accepts, the researcher receives a higher payoff in the form of a higher salary, and the administrator receives a lower payoff in the form of higher costs to keep the researcher. If the administrator rejects either offer, she loses her researcher and the researcher has to start over at a new job, leading to a low payoff for both (Fig. 6).

Game theory indicates the administrator should accept any offer that presents no cost to her, even an 'unfair' one. However, in reality, the administrator, like many real-life players in the ultimatum game, may be unlikely to accept an offer that she views as unfair. Additionally, she may consider the ultimatum to be damaging to the relationship in a

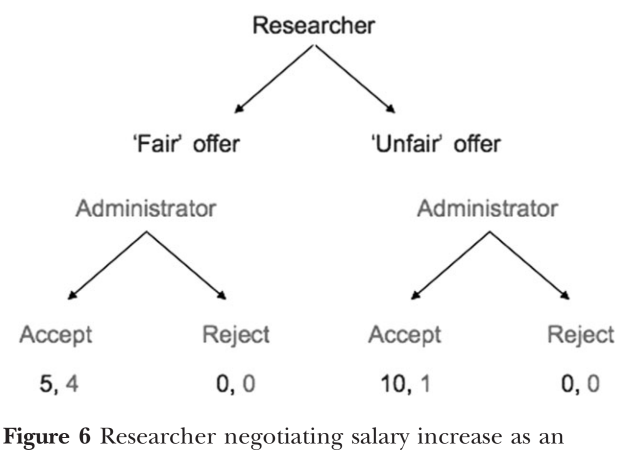

Figure 6 Researcher negotiating salary increase as an Ultimatum Game

way that cannot be offset by a successful negotiation, thereby making any ultimatum offer an 'unfair' one. In practice, players often reject offers that they view as unfair for a variety of reasons, both conscious and unconscious.[1,36–38] In some cases, one player may act in a way that seems irrational, seeming to prefer to take a loss rather than to allow the other player to make a significant gain. However, it is important to keep in mind that the model assumes purely self-interested rationality, whereas to some players, a choice that denies a payoff to both sides may be a type of rational choice.

Additionally, this Ultimatum Game could include counteroffers, with the administrator proposing and justifying a different option in response to the researcher's initial offer, and so on until a bargain is reached. A rejection of a particular offer could be considered a move in a larger strategy; that is, with the expectation of continued interaction, the rejection of the offer could communicate something critical about the recipient's nature or convictions to the player who made the offer. Studies suggest that in a game with multiple rounds, a 75:25 split often serves as the equilibrium ratio,[1] and in one case with repeated rounds, players reached an equilibrium at a 50–50 split.[37] In other words, the researcher may end up with 75% of his initial proposal if the negotiations end quickly, and may end up with something closer to 50% if the negotiations are protracted.

This game emphasises that fairness and open communication about perception of value is critical to both sides' decision-making and thus paramount in reaching a mutually beneficial outcome. Changing the perceived value of the payoff could thus change the outcome of the game. If the researcher presented a strong argument as to why he should get a certain raise based on his value to the institution, the administrator may be more likely to accept an offer that may have otherwise seemed unfair. Similarly, the administrator could make a counteroffer based on what the institution can afford, as well as how she perceives the value of the researcher's contributions, and so on until a mutually acceptable agreement is reached. In more challenging situations, for example where the two sides are unable to agree on a fair split but do not want to end the negotiation, a third party arbitrator could help break a deadlock.

THE CENTIPEDE GAME

The Centipede Game models a scenario in which players make multiple sequential moves. In this

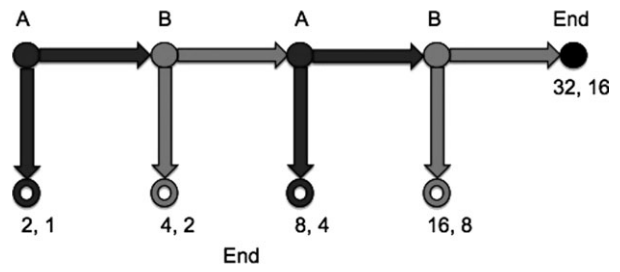

Figure 7 Payoffs in the Centipede Game. This chart details the relative payoffs for each turn in the Centipede Game

game, the players at each turn choose to either take a share of a pot of money and end the game or move the pot back to the other player, allowing the pot to increase but potentially reducing their individual payoff. The traditional game had 100 rounds but it can be played for fewer or infinite turns.

Using our two players to illustrate: Adam starts with two piles of coins, one with one coin and one with two coins. Adam can choose to keep the larger pile and pass the smaller pile on to Barbara, at which point the game ends, or he can pass both piles to Barbara, where they double in size to two and four coins, respectively. Barbara then has the same choices to make: she can either keep the larger pile and end the game, or move both piles back to Adam and allow them to double in size. This continues until one player ends the game or the game reaches a predetermined move limit. The potential payoff for each player is higher the longer the game is played, but the risk of the other player defecting and receiving a higher payoff also increases. Notably, a longer game also presents more opportunities for players to build trust (Fig. 7).

Game theory predicts that a rational player, thinking through the potential moves of the game (in a process termed 'backward induction'), will end the game on the first turn by choosing to keep the larger pile of coins because he assumes his fellow player will pocket the coins on his subsequent turn. Therefore, to maximise his own payoff, he would take the larger pile of coins at the outset. This first-turn defection is the Nash equilibrium for the Centipede Game.

THE CENTIPEDE GAME: RESIDENT AUTONOMY

The Centipede Game can provide a framework for the complex strategic relationship between an attending physician and a trainee. The scenario we will use for the Centipede Game has parallels to the Stag Hunt scenario described in an earlier example, especially in the realm of the role of trust in decision-making in a medical education scenario. Although the Stag Hunt was used to model the motivation of an attending physician and resident to perform their assigned duties in a scenario based on risk and trust, the Centipede Game provides a model that can be used to examine the decision-making process by which an attending physician may assign a resident's duties in a similar context. For an attending physician, determining the level of autonomy a resident should be given is a complex challenge. This decision is often based on a sequential analysis of that resident's skill, abilities and trustworthiness, taking into account the length of time the attending physician expects to spend with the resident during a given rotation. When applying the Centipede Game to this challenge, the attending physician makes the first move: she could choose to 'cooperate' by allowing the resident to see more patients (taking a risk on the resident's maturity and abilities) or could 'defect' by restricting the resident's access to patients. The attending physician may choose to give the resident a greater level of autonomy to provide higher-quality training, even while potentially compromising on some aspects of patient care in the short term. However, the attending physician may defect if she does not know the resident well or is not convinced that the resident has the skills or maturity necessary to provide high-quality care. Additionally, an attending who lacks continuity with a resident, for example seeing that resident for only one or two full days during a several-month rotation, may be less likely to offer initial trust. Although the attending physician's defection may result in higher-quality patient care in the short term, it may also affect the quality of care the resident can provide when he completes his training.

For his part, the resident may choose to cooperate, attempting to learn as much as possible with the opportunities he is given in the hope that the attending physician may give him additional leeway in the next round. Alternatively, he may defect by, for example, cutting corners, displaying a bad attitude or refusing to accept advice on the care of the patients he does get to see. The choice to defect runs the risk that the attending physician will be less likely to give him additional access in the next round.[39]

Even though both sides probably would gain maximum benefit by cooperating early in the relationship, game theory predicts that the attending physician would initially defect to minimise risk and uncertainty, which would probably lead to the resident's subsequent defection to avoid putting in significant effort for little return. Unlike the traditional model of the Centipede Game, however, this game does not literally end when one player defects, but it can figuratively end in the form of an unproductive relationship. The Centipede Game is thus similar to the Stag Hunt in the importance of making a decision about when and how to offer trust, a decision that plays a large role in the outcome of the relationship, and in this case can determine whether the value of interactions between student and teacher increases throughout the relationship.

OTHER APPLICATIONS OF GAME THEORY TO EDUCATION AND MEDICINE

Game theory has not been thoroughly or exhaustively applied to human interactions in the medical field, although some literature exists that discusses its applications to health care scenarios. Decision theory, a similar concept that also considers decision-making under uncertain conditions, has received more attention in the past.[40–42] The limited existing body of literature on game theory in medicine cursorily discusses its applications to medical economics, residency matching, the doctor–patient relationship, medical decision-making and surgical culture. The authors found no literature that explicitly discusses game theory's potential applications to medical education, and very little that considers its applications to education in general.

The existing literature on game theory's applications to the educational environment comes to conflicting conclusions about its effectiveness. Although the models can be used to improve student engagement and the comprehensiveness of students' understanding of complex topics, these models, depending on how they are implemented, also have the potential to create a competitive atmosphere that can undermine educational goals.[5,43–49]

The literature indicates that game theory probably is most effectively applied to education in the realm of curriculum design, a conclusion that corresponds to the scenarios presented above. Game theory models can be used to assess student dynamics and incentives in the learning environment, and thus provide foundations for amending that environment to achieve different goals. For example, a recent article on a popular medical website discussed the issue of medical students' declining motivation to behave professionally during their clinical rotations. In a simple analysis that drew implicitly on game theory principles, the author noted that students have little incentive to significantly alter their behaviour because their evaluations are based almost entirely on test scores and do not take their comportment into account.[50] Another example considers grading scales for students, a similar topic to the one discussed in our Prisoner's Dilemma scenario. A professor at Johns Hopkins graded his students on a curve, whereby the highest score on any exam received the equivalent of 100%, and the rest of the scores were scaled accordingly. The students realised that if they boycotted the final exam, a score of zero would be the highest score, and thereby be assigned a value of 100%. By agreeing to cooperate, the students used game theoretic principles to achieve perfect grades on their final exam, and the professor realised he needed to amend his grading policy.[51]

Alternatively, there may be ways to use game theory models directly in the classroom to illustrate complex strategic concepts. One possible scenario for this type of use in medical education would be training for patient interactions, which are, at their core, a series of strategic, interdependent interactions. The practice of using standardised patients to teach students how to handle both standard and challenging patient encounters touches on several aspects of game theory, although perhaps not explicitly.[52–54] Negotiation is a related topic with similar potential utility to game theory. In addition to negotiating with patients, educators and students regularly must negotiate with each other and with their supervisors. Learning some negotiation techniques in the context of game theory can add to educators' and students' capacity to further both their own interests and those of the greater good. Finally, research into the biological and neural bases of decision-making has the potential to add significantly to our understanding of how and why players act the way they do.[55–57]

Game theory has been applied to strategic interactions in other areas of medicine as well. The Prisoner's Dilemma has been used as a foundational principle of the National Resident Matching Program in the United States.[58] It has also been used to analyse the specific challenges posed by the increasing number of applications to programmes in the Urology Match in the USA,[59] to model interactions between physicians and managed-care organisations,[60] to consider the management and resolution of conflict among physicians,[61,62] and to reflect on various aspects of the doctor–patient relationship.[63–65] One article also describes the doctor–patient relationship, and consultations in particular, as variants of the Stag Hunt and the Centipede Game.[66] Finally, game theory models have also been considered in the context of optimising medical decision-making and maximising expected utility under the conditions of uncertainty that physicians face on a daily basis.[63,67,68]

DISCUSSION

The four scenarios discussed above, which serve as a simplified and idealised view of a particular type of social interaction, can help us identify the motivations that affect strategic thought in medical education and provide a foundation for determining how we may be able to encourage more effective cooperation. In the case of medical education, these examples highlight the importance of trust in ensuring continuing cooperation and ultimately reaching a mutually beneficial outcome. Additionally, it is important to note that rationality in the form of individual gain is not always the primary motivating factor for players in reality, and that the relative payoffs for different solutions may differ based on a particular player's values.

Knowledge of or trust in the opponent can change the outcome of these models. Sally determined that cooperation increases significantly when players have a chance to talk about their strategies before beginning the game, indicating that even a marginal level of knowledge about the other player can be enough to convince some players to take a risk on cooperation.[69] In the case of residency training, for example, even something as simple as creating time for residents and attending physicians to meet to discuss expectations and build knowledge about each other may be enough to encourage cooperation at the outset.

When players cannot communicate ahead of time, iterated versions of the games allow more time for building trust and may present more opportunities to achieve a cooperative result. As an example, in a single-round Prisoner's Dilemma, cooperation is never a rational strategy, as the players can always improve their individual standing via defection. However, a Prisoner's Dilemma with multiple rounds, as described by Axelrod, allows for a more complex strategy to develop and potentially provides a way for cooperation to become a better choice for both players as they have an opportunity to get to know each other in the context of the game and may change their strategies based on what they learn about each other.[70] In reality, Axelrod points out, the number of rounds in a game is not always fixed ahead of time, and strategic interactions do not often occur between two people who have never met before and will never meet again. This is true in the case of medical education as well, where a single, unrepeated interaction is unlikely to occur.

Axelrod devised a way of analysing a variety of alternative strategies, rather than unconditional defection, in a Prisoner's Dilemma game with 200 rounds, and determined that a reciprocal 'tit-for-tat' strategy, in which a player takes a chance by cooperating on the first turn and then mirroring his opponent's strategy on the previous move in each subsequent round (i.e. cooperating if the opponent cooperated in the previous round and defecting if he defected). In this strategy, the player never defects first, and would retaliate against defection, but would cooperate again if the opponent changed his mind. This set of conditions encouraged cooperation on the part of the opponent. This strategy can also be applied to non-simultaneous play, such as the Centipede Game.[71]

Applying the 'tit-for-tat' strategy to the types of scenarios described previously may create a greater probability of cooperation over time if one player is willing to take a risk on cooperation toward the beginning of the interaction, thereby providing a positive foundation on which to build a 'relationship' with his opponent over the course of the game. However, although Axelrod's strategy of reciprocation provides an alternative to universal defection in a non-cooperative game, it still requires risk on the part of the player who must endanger his own payoff to choose to cooperate first, giving this game a similar profile to the Stag Hunt. For a risk-averse player, this strategy may not be appealing enough to overcome the reluctance to jeopardise his individual payoff. Additionally, as Axelrod notes, increasing the number of players and the possibility of miscommunications make this strategy more difficult to employ successfully.[71]

Consider the scenario we used above with the Centipede Game and resident responsibility. The Centipede Game has the potential for multiple rounds and in the case we describe is likely to have more than one. If the attending physician chooses to take a risk on cooperation in the first round of the game, it may make the resident more likely to cooperate as well. If the attending physician employs Axelrod's 'tit-for-tat' strategy, he also has the opportunity to retaliate and forgive as necessary. As the game goes on, both the attending physician and the resident have the chance to revise their choices based on information gained in previous rounds. Therefore, each round presents another opportunity for the resident to demonstrate his worthiness of trust, and for the attending physician to extend that trust to the resident. An increasing length of the game can thus contribute to achieving a cooperative result if the knowledge gained encourages cooperation. Additionally, even if one player chose to defect in an earlier round, he could decide to cooperate in the following round if he discovered new information or his perceived payoff structure changed to better encourage cooperation.

Unlike the traditional Centipede Game, the resident and attending physician have the opportunity to discuss their intentions and perceptions throughout the relationship, which provides additional opportunities for cooperation through trust-building. For example, if an attending physician was hesitant to allow a new resident to see many patients, or reluctant to risk cooperation right away, he might still be able to maintain the relationship by explaining to the resident that he wants him to refine his skills on a few patients before overloading him with more. Similarly, a resident who feels comfortable expressing any feelings of marginalisation to his attending physician may be more likely to cooperate as time goes on. In this way, some honest communication combined with a little bit of risk can have a positive payoff in the form of mutual cooperation.

Another option for achieving a cooperative result in the absence of implicit trust is to allow players to negotiate binding agreements regarding the distribution of the payoffs received from cooperation. This is a more formal way of encouraging cooperation that requires less risk, as there would be penalties for deviating from the agreement. However, this type of solution will not work for all games as it is not always possible to divide the payoff fairly in a way that ensures each player will get at least as much as they would have if they had defected.[23]

The issue of differing concepts of rationality can also complicate game theory models' predictions, as human behaviour is often complex and motivated by considerations other than individual gain. A newer subset of game theory, known as 'behavioural game theory', builds on some of the concepts described by Axelrod. It considers the complicating factor of human behaviour to begin to create more accurate models, although no formal models have yet been codified. One of the main concepts in behavioural game theory, 'bounded rationality', considers that players may be concerned with minimising their losses, but only up to a point. They may have moral standards that motivate cooperative behaviour despite a potentially worse outcome (as in the altruism described in Axelrod's strategy); in other words, their version of rationality may not prioritise individual gain over all else. Conversely, they may be too fatigued or unmotivated to fully consider their opponent's strategy. As a result, the Nash equilibrium may not be the most likely outcome.[23,29,56,66,72–75]

For example, in the Centipede Game, several studies have shown that players frequently try to cooperate for several rounds before ending the game despite the Nash equilibrium of initial defection.[23,76] Similarly, several studies on the Ultimatum Game found that low or 'unfair' offers were frequently rejected, despite the prediction that players should accept any non-zero offer. One study suggests that this behaviour correlates with high testosterone levels,[37] whereas another indicates that oxytocin levels may increase generosity.[57] Sanfey discussed other possible neuroscientific bases for these deviations from rationality, including the role of various neurotransmitters in reward.[38] More generally, however, the concepts of fairness and reciprocity may play a role in players' assignment of relative value to particular outcomes. In addition, as several of the studies suggest, the influence of social institutions and cultural norms can affect the way players view the structure and results of the games. In addition, it is interesting to note two studies by Henrich *et al.* that demonstrate that violations of pure rationality occur cross-culturally, although the specific behaviours (for example, the propensity to accept a large or small offer in the Ultimatum Game) exhibit variability.[77,78] However, variations in individual values and preferences that do not conform to these models could have an equally strong effect on the outcome of a game.

Strategic interactions in medical education will almost certainly be complicated by factors that defy self-interested rationality, and thus change the nature of the models to some degree. For example, consider an attending physician who strongly values his time with his family. Regardless of his commitment to teaching, he has a competing interest that may change his relative perception of the value of a particular outcome in a strategic interaction with his students, and therefore shift the results away from the Nash equilibrium. Alternatively, consider a student from our Prisoner's Dilemma example who is evaluated on a curve but values the process of learning more highly than her individual position within the class. In this case, the equilibrium would also be likely to shift, as she would probably not assign the same relative values to the outcomes that we used in the example. Taking these human factors into account can help with understanding the limitations of the models in a practical sense, even when they may still serve as a useful initial framework for analysis of incentives and potential outcomes.

The importance of trust, the length of the game and personal values are useful markers when looking to determine how to adjust the parameters and incentives of a game to achieve a more mutually beneficial result. These types of solutions may need to be tailored to each set of interactions, as no two will be the same in practice. As an avenue for further research, setting up a series of simulated games among educators and students, as has been done in several of the studies mentioned here, may help identify whether this group has a unique way of assigning value to particular outcomes and whether a consistent type of deviation from the models exists, perhaps because of a similar set of values or as a product of the style and content of the education itself.

CONCLUSION

Game theory provides useful models for strategic interactions that commonly occur in medical training and practice. Physicians encounter situations every day that pit individual rationality against the human condition and the greater good, and to do their job, they must find ways to prioritise the greater good over individual gain.[55,79] Although no model can perfectly account for the idiosyncrasies of human personalities, game theory serves as a useful framework for analysing interdependent strategic behaviour in a variety of health care related situations. Using game theory as an integrative tool, in conjunction with good judgement and a sound knowledge base, trainees and physicians can work to better recognise where competing priorities exist and understand the motivations and interactions of the various players, which can affect their ability to provide the best possible patient care. Ultimately, game theory can serve as a foundation for medical professionals to adjust their approaches to strategic situations and begin to determine ways to adjust the parameters of the game when the preferred outcome is not the most likely one.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Figure S1. Decision-making style and equilibrium type in four game theory models.

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