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EVALUATING INTELLIGENT TUTORING WITH GAMING-SIMULATIONS

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ABSTRACT

Gaming-Simulation is an important pedagogical tool to accomplish learning. However, as an educational tool Gaming-Simulations follow the concept of discovery learning and, therefore, do not necessarily support any direct educational aim. A way to overcome this weakness is to support the Gaming-Simulation with an intelligent tutoring facility. Although it is generally believed that Intelligent Gaming-Simulations promise a great potential for instruction, little work has been done on the development of an appropriate evaluation method to estimate the efficiency of their intelligent tutoring. This paper gives an introduction to Intelligent Gaming-Simulations. It then continues to propose an evaluation method for the assessment of the tutoring abilities of Intelligent Gaming-Simulations.

1 INTRODUCTION

Gaming-Simulation has recently gained considerable popularity as a tool for education and training both in industrial and academic environments (Lane 1995, Shlecher et al. 1992). A Gaming-Simulation is a sequential decision-making exercise, with the basic function of providing an artificial but realistic environment that enables players to experience the consequences of their decisions through immediate response. Its objective is to enhance a comprehensive understanding of complex systems and to communicate and develop knowledge and skills.

A major problem that has frequently been mentioned with Gaming-Simulations is the lack of sufficient conceptual ability on the part of the player to manipulate the Gaming-Simulations in order to gain best insight into the processes and procedures involved (Angelides and Paul 1993). The original version of the Metal Box Business Simulation Game (1978), for example, aims to teach managerial skills to students through experience during game play. However, the game lacks any adaptability to the student since the students are merely provided with a business environment in which they have to direct and organize the game play themselves. As a consequence students are left to allocate their own roles. Furthermore, unfamiliar management tasks, such as pursuing sensible market research, are often avoided rather than attempted due to lack of student support and encouragement, and feedback to student mistakes is restricted to the reaction of the market and lacks any further remedial explanation or advice. Intelligent Tutoring Systems, however, promise to enrich the learning opportunities for players by offering a wider scope for intellectual exploration through individualized player guidance and support within the learning environment. In order to overcome their weaknesses, an increasing number of recent Gaming-Simulations have been developed incorporating an intelligent tutoring facility (Siemer and Angelides 1994, Doukidis and Angelides 1994).

With the arrival of these Intelligent Gaming-Simulations comes the need for an assessment of their full or potential usefulness. The evaluation of an Intelligent Gaming-Simulation influences interest in and support for future research and development. It directs public and professional opinions about the field as a whole and about the marginal usefulness of what is portrayed as progress in education and training. Furthermore, evaluations influence choices to adopt a particular system. In a future where Gaming-Simulations may be widely available in schools, evaluations will shape how and what people learn. These facts call for well developed and appropriate evaluation techniques (Winne 1993).

Although the need to evaluate Intelligent Gaming-Simulations has been recognized, there are currently no generally agreed principles for their assessment (Shute and Regian 1993). The reason for this lack of standard evaluation methods lies in the fact that the work in the field is still young and undertaken by researchers from very different academic backgrounds, such as computer science, education and psychology.

This paper starts with a short illustration of how Intelligent Tutoring Systems provide for intelligent tutoring and continues to illustrate how an intelligent tutoring facility may be integrated into a Gaming-Simulation. It then proposes an evaluation method for the examination of intelligent tutoring within Gaming-Simulations following evaluation recommendations from the field of Intelligent Tutoring Systems.

2 GAMING-SIMULATIONS FOR TEACHING AND LEARNING

The purpose of both simulations and games is to provide an environment that facilitates learning or the acquisition of skills (Taylor and Walford 1978). Simulations do so by mimicking reality and games by providing the student with entertaining challenges. The purpose of games is to tutor and as such to convey a variety of information like facts and principles, processes, the structure and dynamics of systems, problem solving skills, decision making or strategy formulating, social skills such as communication, the nature of competition, how people cooperate, the dynamics of social systems, the role of chance, and the fact that penalties often occur for just and for unjust reasons. Games tend to motivate students (Lardinois 1989) and focus their attention on the goal of the game, and hence enhance the learning environment because the teacher plays a less dominant role and is not the only judge of performance.

The term 'game' is applied to those simulations which work wholly or partly on the basis of players' decisions (Lane 1995). Within the simulated environment players have goals, sets of activities to perform, constraints on what can be done, and payoffs (good and bad) as consequences of the actions. The elements in a Gaming-Simulation are patterned from real life: roles, goals, activities, constraints, and consequences, and the linkages among them simulate those elements of the real-world system. Therefore, Gaming-Simulation is a hybrid form, involving the performance of game activities in simulated contexts. These may range from fairly simple decision-making exercises lasting no more than a few minutes to extremely elaborate simulations which may take a considerable amount of time for the completion of a single round of decision-making. The general aim of these games is to communicate principles and skills in such diverse areas as marketing, production, stock control and labour relations. Gaming-Simulation can serve as a predecision tool to link a more complex model to the real world.

Gaming-Simulations are currently utilized both in industrial and academic environments for a variety of purposes: heightening interest and motivation, presenting information and principles, putting students or trainees into situations in which they must articulate positions, ideas, arguments or facts they have previously learned, or training them in skills they will later need. However, with Gaming-Simulations the students or trainees learn by performance rather than through a Socratic discourse. One problem that often arises with Gaming-Simulation is the lack of sufficient conceptual ability on the part of the student to manipulate the Gaming-Simulation in order to gain the necessary insight into the processes and procedures involved.

However, the use of Artificial Intelligence in computer based training has provided interactive learning sessions with the capability to guide the student's exploration of the task domain being learned (Angelides and Gibson 1993). This gave birth to perhaps the most sophisticated form of computer based training systems, that of the Intelligent Tutoring System.

3 INTELLIGENT TUTORING SYSTEMS

With Intelligent Tutoring Systems we have entered a new era in the teaching of and learning by students (Angelides 1992). Intelligent Tutoring Systems go beyond the drill and practice of the traditional computer based training systems. Information technology now allows us to develop computer-based tutors to instruct students on an individual basis. Intelligent Tutoring Systems provide for helpful guidance and make the teaching process more adaptable to the student by exploring and understanding the individual student, the student's special needs and interests, and by responding to these as a human teacher does. An Intelligent Tutoring System allows for errors to occur and provides the student with feedback and associated remedial action. In order to provide this adaptability to the student an Intelligent Tutoring System makes use of its three knowledge models, i.e. the domain model, the tutoring model and the student model (Winkels 1992).

The *domain model* includes an explicit representation of the domain-specific knowledge and the problem solving knowledge of the topic, which the Intelligent Tutoring System intends to teach the player. This enables a comparison to be made between the behaviour of the user against that of the 'expert'. Intelligent Tutoring Systems are also equipped with teaching expertise which is contained in their *tutoring model*. An Intelligent Tutoring System has the ability to perform diagnoses of the user's current knowledge, missing conceptions and misconceptions about the subject area being taught. This is achieved by collecting feedback from the student during the course of interaction and by being able to analyse this feedback against a wide range of predefined student behaviours. This information about the student is stored in the *student model*. The system uses this information to tailor its instruction according to the needs of the individual student. Most Intelligent Tutoring Systems are also equipped with the ability to help their students clear away any misconceptions and acquire any missing conceptions. An Intelligent Tutoring System possesses the ability to guide the user's exploration of the subject being learned and provides assistance on demand.

Suggestions have been made to use these characteristics of an Intelligent Tutoring System and develop Intelligent Gaming-Simulations that assist players with their decision making (Angelides and Paul 1993). The following section outlines how an integrated intelligent tutoring facility may support a Gaming-Simulation in order to foster the players' learning as well as monitor and provide feedback on their behaviour and performance during game play.

4 INTELLIGENT GAMING-SIMULATIONS

Considering the tasks the integrated intelligent tutoring facility is set to perform to increase the pedagogical value of a Gaming-Simulation, its three knowledge models (domain, student, and tutoring model) should include several pieces of knowledge (Angelides and Paul 1993). The *domain model* should include knowledge about a wide range of games from which it can select a game according to some teaching goals dictated by the tutoring model or according to the context of players' student models which is dictated by the student model. The domain model should be able to explain the reasons for choosing a game, the rules, the initial scenario and the roles of the game and be able to provide explanations about the game at any stage. The domain model should not only have knowledge about these but also be able to use them. For example, should it detect a deviation from the rules, it should warn the player and may also offer to help apply them correctly. In another case, it may have to execute the game model in order to test some unanticipated conditions. In addition, the domain model should include a bugs library of all common misconceptions about a game. The intelligent tutoring facility should be able to generate from its own knowledge all the materials that are to be handed out to the players. The domain model should also have knowledge about role assignment, priority of roles, the number of people in a role and how to allocate roles. This would partly require access to the student models to determine who should or should not be allocated to particular roles. However, initially the domain model may have to allocate roles randomly since there will be no prior knowledge included in student models of any of the players. The step to step move will be dictated by the tutoring model which is in control of that process as well as the time parameters.

The *tutoring model* should include knowledge about the teaching goals associated with every game, the cycle sequence, the steps of play, and a set of teaching strategies. The tutoring model supervises the flow of the game through the steps of play and, being in control of the time mechanism, it controls all of the time parameters. Should an error occur, the tutoring model initiates remedial tutoring for the player diagnosed to suffer from the error. All the activities of the tutoring model are under the control of the teaching strategy which the tutoring model currently employs to let the game flow.

The *student model* includes the current knowledge of the player about a game, especially the rules of the game, the roles he took over during the game play, the steps he went through with every role, his performance with each one of these roles, whether he is able to select the right decision making strategy in a given situation, whether he can apply the decision strategy right, etc. In addition, the student model should include a record of all those misconceptions the player has been diagnosed to suffer from, such as the incorrect application of a game rules, and whether these have been remedied at any stage during the game. The student model should also include an overall classification of the user (i.e. beginner, advanced, expert, etc.) along with those pedagogical goals that the player has demonstrated to have satisfied, and some indication of where his strengths and weaknesses lie in relation to the game (for instance, making decisions in unanticipated situations). Finally, the student model may include some personal details like, how quick the player is in making decisions, whether he plays safe, whether he is risk aversive, whether he is aggressive, etc. The intelligent tutoring facility uses a player's student model to provide individual tutoring where and when necessary. Furthermore, the student model is a useful source of information during game play because it provides the basis on which the system can make decisions about distributing further resources, assigning roles, providing game progress reports to the individual, controlling time parameters (e.g. more time to less aggressive players) and engaging the player in remedial actions. In addition, the student model is a valuable source of information for postplay evaluation not only of individual players but also of the system itself. The feedback which the student model can provide can be used by the game designer as input to another round of the game, for the development of initial player student models and also to improve the Gaming-Simulation and in particular the executable game model represented in the domain model.

INTUITION, the implementation of the Metal Box Business Simulation Game, is an example for such a Gaming-Simulation Environment which integrates an intelligent tutoring facility to improve its pedagogical effectiveness by guiding the players through the game and offering them help when the need arises (Siemer and Angelides 1994). The integration of the intelligent tutoring facility involved the extension of the Gaming-Simulation Environment by the three standard intelligent tutoring knowledge sources, i.e. additional domain or gaming knowledge, a tutoring model, and a student model for each player.

The additional domain knowledge allows INTUITION to use alternative explanations of concepts, e.g. in form of an example or an analogy, the student is found to have problems with. The integration of tutoring knowledge enables INTUITION to use teaching strategies which allow the system to follow a clear and attainable educational learning goal for each player, to manage market resources and to control the decision making processes accordingly. Eventually, INTUITION incorporates a student model for each player. The student model includes a library of all common errors to support error diagnosis. At the same time it represents the player's current knowledge about the game, the role he plays in the current game and the roles he played in previous games, his performance during the different steps of the current and previous games and how well he managed the resources he was allocated by the system. The student model is a useful source of information during game play, because it provides the basis on which the system's accounting system can make decisions, such as further distribution of resources and role re-assignment. Additionally, the student model contains the necessary information for error diagnosis and remediation.

INTUITION is an example for a system which attempts to increase the pedagogical value of a Gaming-Simulation through the integration of an intelligent tutoring facility. As Intelligent Tutoring System issues are explored and employed to develop Intelligent Gaming-Simulations such as INTUITION, methods to evaluate the pedagogical effectiveness of these systems become increasingly important (Mark and Greer 1993). In order to assess the educational value of an Intelligent Gaming-Simulation the following section borrows from evaluation methods that have been suggested in the field of Intelligent Tutoring Systems and adapts them for the evaluation of the intelligent tutoring with Intelligent Gaming-Simulations.

5 EVALUATING INTELLIGENT GAMING-SIMULATIONS

The purpose of this section is to propose an evaluation method for intelligent Gaming Simulations. Research in the field of Intelligent Gaming-Simulations is still young and lacks a standard evaluation method. However, since the intelligent tutoring facility of an Intelligent Gaming-Simulations is based on the architecture of an Intelligent Tutoring System we can borrow ideas from this field.

The evaluation methods that have been used or developed for Intelligent Tutoring Systems to date have emerged from evaluation methods proposed by researchers from very different academic backgrounds, such as computer science, education and psychology (Mark and Greer 1993). Researchers currently decide on a particular evaluation method depending on their interests and concerns. However, the research interests and concerns can be divided into two generic categories which are manifested in the use of either *external* or *internal* evaluation methods which can be adapted for the evaluation of Intelligent Gaming-Simulations as outlined below (Littman and Soloway 1988).

The internal evaluation of an Intelligent Gaming-Simulation addresses the question: *'What is the relationship between the architecture of the intelligent tutoring facility and the behaviour of the Intelligent Gaming-Simulation?'* The question assesses the inner workings of an Intelligent Gaming-Simulation, by constructing the picture of the architecture of the intelligent tutoring facility and its relationship to the system's behaviour.

The external evaluation of an Intelligent Gaming-Simulation addresses the question: *'What is the educational impact of the Intelligent Gaming-Simulation on students?'* This question assesses effects that are external to the Intelligent Gaming-Simulation, i.e. the player's learning, by examining how the Intelligent Gaming-Simulation helps players to improve or expand their knowledge and problem solving skills.

The answers the two resulting classes of evaluations provide to these two questions illustrate how the design and implementation of the system lead to the system's behaviour and how this behaviour may affect the player.

5.1 Internal Evaluation

The purpose of internal evaluation is to provide a clear picture of the architecture of the intelligent tutoring facility and to determine how this architecture provides for the system's behaviour. To clarify the relationship between the three main components of the intelligent tutoring facility and the behaviour of an Intelligent Gaming-Simulation, an Intelligent Gaming-Simulation can be characterized in terms of answers to the following three key questions:

- ***What does the intelligent tutoring facility know?*** This question is addressed by an analysis of the system's domain, student and tutoring knowledge in respect to what the Intelligent Gaming-Simulation can possibly do based on the knowledge its intelligent tutoring facility is able to provide.
- ***How does the intelligent tutoring facility do what it does?*** Answering this question assesses whether the system performs in the way the designer intended it to behave. This question is answered by analyzing the Intelligent Gaming-Simulation to determine how its processes generate the system's observed behaviour.
- ***What should the Intelligent Gaming-Simulation do?*** This question is addressed by examining the overall capabilities of the system's teaching processes.

According to Littman and Soloway (1988) these three questions are addressed by performing *Knowledge Level Analysis, Program Process Analysis and Tutorial Domain Analysis*:

Knowledge Level Analysis attempts to characterize the knowledge provided by the Intelligent Gaming-Simulation and hence answers the first question: *What does the intelligent tutoring facility know*? It provides useful information about whether the intelligent tutoring facility has sufficient and appropriate knowledge about the domain, the student and tutoring in order to meet the requirements that were set for it. It is not concerned with how and when the system uses or manipulates this knowledge in order to provide for student guidance. Accordingly, knowledge level analysis has to address issues, such as the scope of the system's domain, student and tutoring knowledge and whether the knowledge representation is appropriate.

Program Process Analysis answers the second question: *How does the Intelligent Gaming-Simulation do what it does*? Program process analysis examines whether the intelligent tutoring facility does what it does in the right way. In contrast to knowledge level analysis, which asks whether the intelligent tutoring facility is able to perform certain input-output tasks, program process analysis looks just at how a system uses and manipulates its intelligent knowledge for the purpose of game play. Program process analysis may consequently investigate the expertise, i.e. the way domain knowledge is used and manipulated, the diagnostics, i.e. procedures used by the system to analyze the input of the student to maintain the student model, and the didactics, i.e. the way teaching goals are determined and teaching strategies are used to guide the game. Eventually, program process analysis may assess the overall system control which coordinates the interaction between the system's three knowledge models.

Tutorial Domain Analysis answers the third question of *what the Intelligent Gaming-Simulation should do* by emphasizing any lack of tutorial abilities in any of the three standard knowledge components of the intelligent tutoring facility. These tutorial capabilities are generally specified at the outset of the system implementation stage. However, tutorial domain analysis during the implementation process may sometimes change the limits of the tutorial domain, i.e. the system requirements, with the result that part or all of the three knowledge models may require alteration or extension.

The result of these three analyses intend to provide a picture of whether and how all the knowledge models provided by the intelligent tutoring facility within a Gaming-Simulation, i.e. the domain model, the student model and the tutoring model, provide for the system's desirable behaviour. Consequently, these analyses involve a thorough investigation of the behaviour of the Intelligent Gaming-Simulation under evaluation. In order to carry out such an investigation it is necessary to define what exactly constitutes the behaviour that an Intelligent Gaming-Simulation should display in a teaching situation. A popular representation of such desirable intelligent behavioural properties is a set of evaluation questions (Ford 1988). Since the details of the desirable intelligent behaviour depend on the gaming domain of the Gaming-Simulation under evaluation, the establishment of the specific evaluation questions is generally left to the judgment of the evaluator (Mark and Greer 1993).

In addition to an examination of the relationship between the architecture of an Intelligent Gaming-Simulation and its behaviour, a complete evaluation also requires the examination of the effect of the system's behaviour on the student: The Intelligent Gaming-Simulation has to be evaluated externally by the users themselves before it is put into operation.

5.2 External Evaluation

External evaluation assesses the educational impact an Intelligent Gaming-Simulation may have on the player. It examines how an Intelligent Gaming-Simulation helps the player to improve his knowledge and skills. At the same time external evaluation may assess the more general issue of user satisfaction with the system (Conrath and Sharma 1993). External evaluation, therefore, aims at an overall conclusion or estimate about the system, such as the more fundamental needs concerning the system's usefulness to the player, like its ability to

- foster learning, which is generally referred to as *learning achievement*, and to
- motivate and satisfy the student, described as the *learning affect*.

5.2.1 Learning Achievement

Learning achievement as an overall impact of an Intelligent Gaming-Simulation includes aspects such as the acquisition and the understanding of, and the performance with, the player's knowledge. The dominant approach to assess learning achievement of students with earlier tutoring systems, such as Computer Aided Instruction systems, has been through determining whether students correctly responded to test questions. However, such an evaluation which focuses on correct and incorrect answers does not adequately reflect the mental processes underlying the answers. With the emergence of Intelligent Tutoring Systems and Intelligent Gaming-Simulations came the request to assess the reasons why students give correct and incorrect answers and make correct and incorrect moves within a game by determining how well the system teaches users the knowledge and skills that support the mental processes required to solve certain problems or make particular decisions.

Intelligent Gaming-Simulations reason about the student's problem-solving behaviour, i.e. they apply diagnostic processes, in order to build up a student model that provides information on the understanding of the student's knowledge and skills. In return, this information is used to interpret the student's behaviour and to guide game play. We can distinguish between those student modelling techniques that are based on process models, which capture problem solutions in a supposedly humanlike way, and those student modelling techniques which are not based on process models (Angelides 1992).

The student model of the Lisp Tutor, for example, is based on a process model of how students write simple Lisp programs and is embodied in the GRAPES simulator. The Lisp Tutor uses this simulator to simulate the problem solving process of the novice Lisp programmer when he writes a simple Lisp program. Hence, the student model is represented in terms of what the GRAPES process model did to solve the programming problem.

The WUSOR game (Goldstein 1982), on the other hand, is an example for a system with a student model that is not based on the process modelling technique. WUSOR incorporates a list of skills which the student is expected to acquire. The student model consist of the skills that have been checked off in WUSOR's representation of skills. WUSOR does not try to play the game as a student would in order to build its student model.

Independently of whether or not student modelling techniques are based on process models that simulate students' behaviour, they can be used to assess how well an Intelligent Gaming-Simulation teaches problem solving knowledge in the domain. Littman and Soloway (1988)

first proposed the use of student modelling techniques to support a new approach to external evaluation. They suggested that student modelling techniques, for example, can help to construct a range of problems that the student should be able to solve. These problems can then be used to test the student. The success rate of the student is a measure for the student's learning achievement. A correct student problem solution indicates that the underlying processes or knowledge and skills have been taught successfully by the system.

In this context student modelling techniques based on process models can be used to predict the actual process the student has to go through to solve problems whilst student modelling techniques that are not based on process models can be used to determine some of the knowledge and skills the student has to use to solve problems.

Therefore, the evaluation of early tutoring systems which focused on correct and incorrect answers is different from the evaluation of Intelligent Gaming-Simulations which assess the reasons why players make correct and incorrect decisions or moves. In the external evaluation of the Intelligent Gaming-Simulation the criterion is not how many of the players' answers are correct but how well the game teaches underlying fine-grained skills that support the player's problem solving processes within the game.

Littman and Soloway's evaluation of PROUST (1988) which teaches Pascal programming represents an example of how the student modelling technique of a system can be used to evaluate its learning achievement. The objective of this evaluation was to investigate whether PROUST helps students to avoid and repair Pascal programming bugs. The evaluation was based on PROUST's student modelling technique that is based on the following simplified concept: A novice Pascal programmer reads a problem statement, identifies goals from it to be attained and then selects and implements plans to achieve these goals. This model was used to identify particular programming bugs with which students typically have problems. In order to measure the effect of PROUST's identification of bugs, tests were designed based on PROUST's student modelling technique in which the student had to detect and repair incorporated bugs. The results from a group of students who had used PROUST were compared with those from a group who had not used PROUST. The result of these tests supported the claim that PROUST helps students to detect program bugs. However, it also proved that simply identifying bugs for students is not enough to achieve radically improved student performance.

5.2.2 Learning Affect

The affect of game play is concerned with aspects such as attitudes and emotions caused by the Intelligent Gaming-Simulation. Motivation in the context of learning can be viewed as an indication of the student's willingness to be active and involved in the learning process and is therefore recognized as an important factor of learning. Various ways of assessing the motivating impact of systems have been suggested. Motivation is often assessed by asking the player to simply rate his agreement with specific issues, such as attitudes and activities. Comparisons of time spent on task-related and task-unrelated material during a game are another indicator for the motivation of the player. Also the drop-out rate, i.e. the overall time spent playing a game, indicates the level of interest of the player.

Measuring motivation provides an indication for how players feel about a particular system. The extent of motivation in return may provide information about the learning achievement since such motivation contributes towards the actual learning achievement discussed in the previous section. At the same time the motivation of players working with a particular system suggests whether the Gaming-Simulation will be accepted and used.

The assessment of motivation is generally carried out within experiments with students (Mark and Greer 1993). Such experimental evaluations may be complemented by student interviews or questionnaires. It is left to the system developer and his knowledge about the system's goals to design the questionnaire in such a way that it addresses the research question under examination. Experimental research enables researchers to examine whether the implementation of a system or part of a system has been successful in the sense that it is accepted by the players. It also gives information about the relationships between teaching interactions between player and system and the teaching outcome.

6 CONCLUSION

The use of Gaming-Simulation for education and training purposes is in the increase. A problem with traditional Gaming-Simulations is that the player lacks sufficient conceptual ability to use the Gaming-Simulation in such a way that its teaching benefits are optimized. Intelligent Tutoring Systems, however, promise to enrich the learning opportunities for students by providing individualized student guidance and support within the teaching environment. Therefore, to provide for greater player adaptability, more recently developed Gaming-Simulations incorporate an intelligent tutoring facility.

Whilst these Intelligent Gaming-Simulations have become increasingly widespread teaching environments they lack a formal evaluation of their educational potential. Little work has been done on the development on an appropriate evaluation method to determine whether an Intelligent Gaming-Simulations meets its promised educational usefulness and benefits. However, the evaluation of these educational systems is becoming increasingly important.

This paper has therefore proposed an evaluation method to examine the tutoring abilities of Intelligent Gaming-Simulations. This evaluation method consists of two major assessments. Whilst internal evaluation assesses the inner workings of an Intelligent Gaming-Simulation, external evaluation assesses the educational impact the Intelligent Gaming-Simulation may have on players. The result of this two part evaluation will reveal the educational worth and value of Intelligent Gaming-Simulations, i.e. their strengths and shortcomings, and may thereby influence interest in, and support for, future research and development.

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