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INTELLIGENT TUTORING SYSTEMS: A SYSTEMATIC REVIEW

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Abstract: *Incorporation artificial Intelligence (AI) techniques into learning can be used to produce educationally useful and personalized computer systems known as Intelligent Tutoring Systems (ITSs). ITSs are complex, integrated software systems that use different learning strategies to increase or correction of learner's knowledge. They are intended to support and improve the teaching and learning process in the chosen field of knowledge while respecting the individuality of the learner. AI techniques enable ITSs to deliver guidance and instruction or evaluate learners by customizing the learning experience based on factors such as pre-existing knowledge, learner's preferences, learning style, motivation, and the learner's progress through the learning content. This systematic review reports key information about existing systems and the different features across different educational fields. An overview of used AI techniques used in analyzed systems is given.*

Keywords: *eLearning, artificial intelligence, intelligent tutoring system*

1. INTRODUCTION

The emergence of Intelligent Tutoring Systems (ITSs) has significantly changed the content and practice of teaching and learning in today's learning environments [1]. ITSs represents systems designed to replicate the effectiveness and efficiency of traditional tutoring within computer-based, digital tools and environments [2].

Incorporation Artificial Intelligence (AI) techniques into ITSs aims to provide learning in a meaningful and effective manner with the goal to interact with learners with one-on-one, personalized tutoring approach, similar to a human tutor, automatically enabled by using a variety of computer technologies [3][4]. Unlike other computer-based learning environments, ITS systems analyze each learner's actions and characteristics and, based on their background and the learning progress, provides personalized instructions such as additional learning content and explanations, hints, examples, demonstrations, etc. [5]. In recent years, ITSs have clearly shown that learners can make rapid progress and improve their motivation, knowledge, performances and skills in specific areas [1].

The fact that ITSs field has a long history of productive research and continues to grow, it is evident that this field warrants important consideration regarding the major differences in research goals, terminologies, theoretical frameworks, and emphases among ITS researchers. Research on ITSs aims to: (i) provide computer-based, intelligent sophisticated tutors that know what they teach, whom they teach, and how to teach, and (ii) to develop and test models about the cognitive processes involved in the process of teaching/learning [6]. Consequently, ITS researchers are required to have a good understanding of computer science, cognitive psychology, and educational research, resulting in competing demands [5].

The intelligence of ITS represents applying artificial intelligence techniques and methods in different aspect of the learning process, principally in four main components of typically ITS architecture [7]-[9]:

1) The Domain model
2) The Learner model
3) The Tutor model
4) The User interface model

The domain model (also known as the cognitive model/expert knowledge model) represents the knowledge of the particular domain to be taught and the knowledge that the student wants to learn (domain knowledge) [10]. It consists of the concepts, facts, rules, and problem-solving strategies of the domain in context to be taught [11]. The second component is the student or learner model consisted from different learner's characteristics gathered and updated from ITS's environment during the process of learning, such as the level of knowledge, skills, preferences, actions, responses, behaviors, learning styles, student's knowledge deficiency, etc.[12][13]. The tutor model (also called teaching strategy or pedagogic module) use the learner model, detects the knowledge deficiency in students and based on its own tutoring goals, to devise the pedagogic strategies and methods of teaching [14]. Core components of the tutor model represent: adaptive feedback, hints, recommendations for additional learning content, navigation of the learning path, and presenting adaptive educational content to each individual learner [15]. The last module is the user interface model which represents front-end of the ITSs and provides communication part

for controlling the interaction between user and system [16]. How the main factors for user-acceptance of the system are user-friendliness and presentation, this module integrates all types of information needed to interact with learner, through graphics, text, multimedia, etc.

In order to better understand the challenges that ITSs face, in the relevant literature have been some reviews of ITSs with the focus of the examination of the: (i) applying AI techniques in eLearning systems in order to improve the personalization of learning process [17][18], (ii) inspecting the effectiveness and usability of ITSs [1][19], and (iii) ITSs for specific knowledge area or game-based ITSs [20]-[22]. An analysis of the available review papers has revealed that some questions remain unanswered. Therefore, this paper aims to provide a comprehensive view of ITSs developed across all educational fields, consider different information and their characteristics, applications with particular emphasis on considering applied AI methods.

This paper is organized as follows: Section 2 describes the research questions. Section 3 represents the used methodology for data collection and analysis. Section 4 discusses the found results. Finally, Section 5 concludes this paper.

2. RESEARCH QUESTIONS

A systematic review focuses on research questions that try to identify, appraise, select and synthesize all high-quality research evidence about ITSs.

The following research questions were formulated:

RQ1: Which AI techniques have been used in ITSs?
RQ2: What adaptive features/purposes of the ITSs have been used?
RQ3: In which educational fields ITSs have been used/evaluated?
RQ4: What types of user-interface have been used in ITSs?

3. METHODOLOGY

In order to address the research problem, papers related ITSs and applying AI techniques in eLearning systems were considered during the systematic review as shown in Figure 1. Preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines were used [23].

Papers were searched within the period from 2009 to 2019 from the Web of Science, Google Scholar, Research Gate, Academia databases and by using backward referencing from papers cited within the literature that met the inclusion criteria. Some of the papers are taken from similar review papers about ITS filed with their reached conclusions.

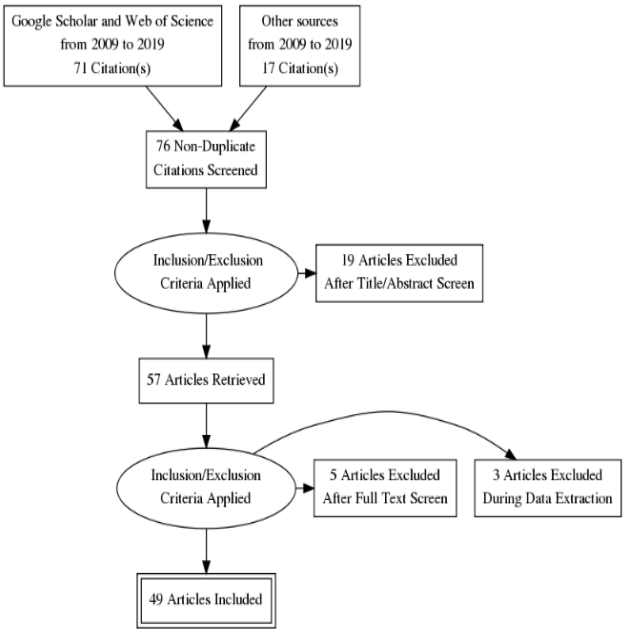

Figure 1: The process of PRISMA for data collection and analysis[1]

3.1. Search string

Within the research field there are multiple terms that relate intelligent tutors. The PICO criteria were used to define the search string [24]:

- Population (P): intelligent, adaptive, personalized learning systems OR environments OR tools,
- Intervention (I): student OR teacher OR instructor learning OR education OR tutoring
- Comparison (C): other (medical staff, pilots, etc.) training
- Outcome (O): effective learning

Used search string was: (intelligent OR adaptive OR personalized learning systems OR environments OR tools *for*) AND (student OR teacher OR instructor learning OR education OR tutoring) OR (medical staff OR pilots training *in order to achieve*) AND (effective learning).

3.2. Inclusion and Exclusion Criteria

Collected papers were evaluated based on the following inclusion and exclusion criteria:

1. Only journal and conference papers were included. Reviews, abstracts, news, editorials, and web resources were excluded.
2. The papers closely related to ITSs were included. The game-based ITSs, non-intelligent adaptive or personalized education systems, partially prototyped ITSs without evaluation and studies that used commercial adaptive eLearning platforms without improving were excluded.

[1] Retrived by PRISMA Flow Diagram Generator http://prisma.thetacollaborative.ca/

3. Only papers published from 2009 to 2019 were included.
4. Only papers reported in English were considered.

3.3. Data Extraction

Once articles were identified as meeting the criteria for inclusion the full-text of papers was read once again in order to extract the following variables: (i) the name of the proposed system, (ii) AI techniques that were used, (iii) field of education, (iv) adaptive features from proposed ITSs, (v) purposes of extracted adaptive features and (vi) details about user interface.

4. RESULTS AND DISCUSSION

RQ1: Which AI techniques have been used in ITSs?

The most commonly used AI techniques in ITSs with the intention to support and improve the teaching and learning process while respecting the individuality of the learner are listed in Table 1. It can be seen that Condition-action rule based reasoning and Bayesian based techniques are most common. On the other hand Case-based reasoning is researched in the least amount of papers.

Table 1: Frequencies of used AI techniques in the ITSs.

AI Techniques	References	%
Condition-action rule based reasoning	[26], [27], [31], [33], [35], [37], [40], [41], [42], [55], [57], [60], [61], [62], [64], [66], [67], [68]	36.73%
Bayesian based techniques	[26], [28], [29], [44], [45], [46], [48], [49], [51], [63] , [64], [65], [69]	26.53%
Data mining techniques	[27], [31], [36], [41], [56], [61], [64], [65], [67]	18.37%
Fuzzy based techniques	[34], [38], [39], [43], [53], [54], [71]	14.29%
Other techniques	[52], [58], [59], [70], [72]	10.20%
ANN based techniques	[47], [50], [52], [56], [71]	10.20%
Intelligent agents	[25], [67], [69], [71], [73]	10.20%
NLP based techniques	[32], [35], [50], [69]	8.16%
Case-based reasoning	[30]	2.04%

RQ2: What adaptive features/purposes of the ITSs have been used?

As mentioned before, AI techniques enable ITSs to deliver guidance and instruction or evaluate learners by customizing the learning experience based on factors such as pre-existing knowledge, learner's preferences, learning style, motivation, and the learner's progress through the learning content. Adaptive features and purposes of applied AI techniques in ITSs are summarized in Table 2.

Table 2: The adaptive features and purposes of applying AI techniques in ITSs.

Adaptive features/ purposes of ITSs	References	%
Personalized feedback, hint or recommendation	[25], [27], [28], [33], [35], [36], [38], [41], [42], [45], [46], [50], [57], [58], [59], [60], [61], [64], [66], [67], [68], [69], [70], [71], [73]	51.02%
Classification, clusterization and updating learner's characteristics (learning style, needs, skills, etc.)	[27], [28], [29], [32], [34], [36], [38], [39], [41], [43], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [61], [64], [65], [68]	48.98%
Learner's knowledge, performance or skills evaluation	[25], [26], [30], [31], [32], [33], [35], [36], [41], [44], [56], [58], [59], [60], [62], [63], [65], [66], [67], [69], [70], [71], [72], [73]	48.98%
Presenting adaptive personalized learning material or content	[26], [27], [37], [40], [42], [43], [45], [52], [53], [54], [55], [57], [60], [62], [66], [67], [69], [71], [73]	38.78%
Adaptive or personalized learning path navigation	[32], [37], [42], [46], [57], [60], [62], [66], [67], [68], [69], [71], [72], [73]	28.57%
Presenting adaptive test and exercises	[31], [54]	4.08%

RQ3: In which educational fields ITSs have been used/evaluated?

The frequency of educational fields in ITSs are given in Table 3. It is evident that the ITSs are mainly used in computer science education.

Table 3: Frequency of educational fields in ITSs.

Educational fields	References	%
Computer Science	[27], [29], [30], [34], [38], [39], [42], [46], [52], [53], [54], [57], [58], [59], [61], [63], [65], [67], [68], [69], [73]	42.86%
Health/Medical	[25], [26], [32], [48], [49], [51], [70]	14.29%
Mathematics	[28], [55], [60], [62], [64], [66]	12.24%
Language	[36],[37], [40], [50], [71]	10.20%
Physics	[35], [45], [56]	6.12%
N/A	[41], [44], [72]	6.12%
Others	[43], [47]	4.08%
Artificial Intelligence	[31], [33]	4.08%

RQ4: What types of user-interface have been used in ITSs?

Important part of ITSs represents user interface infrastructure. The results show that the web-based user interface is the most frequent (97.96%) for the development of ITSs, while only 2.04% of ITSs user interfaces are mobile-based.

5. CONCLUSION

This paper analyzed intelligent tutoring systems across different educational fields and artificial intelligence techniques used in order to deal with different challenges, such as providing computer-based, intelligent sophisticated tutors that know what they teach, whom they teach, and how to teach, and developing cognitive models involved in the process of teaching/learning This work included 49 reviewed papers. It was concluded that the most used AI technique in e-learning is Condition-action rule based reasoning, while the most frequent educational field was Computer science.

Although, research on ITS provided many interesting theoretical insights, there are relatively few ITSs which are really used in schools. Therefore, future work will analyze a larger number of papers with greater emphasis on practical usage of proposed ITSs in educational environments.

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