Chapter 3
Overview of Simulation in Higher Education: Methods and Applications

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Abstract Simulation is one of the most widely used methodologies in many areas such as industry, army, leisure activities, and education. This chapter is devoted to simulation in higher education (HE) and its use for administrative and educational purposes. Many types of simulation models have been used in HE for various purposes. Literature reviews have been published on specific types of simulations in HE but, to the best of our knowledge, there has not been a comprehensive overview of all types of simulation models in HE. We classify simulation models in HE into two types: (a) *analytic simulations* models such as discrete event simulation and system dynamics, and (b) *educational simulation* models such as, virtual reality, games, and simulators for training. This overview presents examples for each method, which gives some idea of the specific areas of HE they were used for. Moreover, taxonomy tables summarize the number of articles published over the last 20 years for each simulation method in HE in the Web of Science, along with the *area of applications* they are used for in HE. The number of articles on *educational simulations* is larger by far than the number of articles on *analytic simulations*. This overview is useful for developers of HE simulations and for administrators in HE institutions.

Keywords Higher education · Simulation · System dynamics · Discrete-event simulation · Agent-based simulation · Educational simulation · Simulator · Educational game · Virtual learning

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3.1 Introduction

Simulation is a model which imitates a system or a process behavior to learn about the system over time (Yang, 2014). Simulation is used in many areas such as industry, business, military, engineering, city planning, medicine, leisure activities, and education. Banks (2009) defines "modeling and simulation" as an academic discipline with its own research methodology. Ideally, simulation has several steps, the first of which is building a model that approximates a real-world event. Such a model, which is usually computerized, often includes its own dynamics and involves repetitions and data collection. This step is followed by the analysis of the data and the drawing of conclusions (often with visualization). Ideally, the final steps are verification and validation of the model. This chapter is devoted to simulation in higher education (HE) and its use for administrative and educational purposes.

Simulation is a multidisciplinary method that advances technology. In 1999, the NSF officially declared simulation as the third branch of science (ibid., p. 3). There are many general simulation journals (e.g., *Journal of Simulation*), in addition to those focused on specific disciplines (e.g., *Simulation in Healthcare*, Simulation, and International Journal of Simulation Modeling) or on a specific sub methodology (e.g., *Simulation and Gaming*). Moreover, several disciplines (e.g., operations research, computer science, and industrial engineering) include simulation as a subdiscipline, some even offering a required course in simulation in their academic program either on how to build or apply a simulation model. Others just use simulation models for educational training (e.g., simulators and games). Almost all disciplines (and often subdisciplines) in HE have their own types of simulation models, including the following: games in business studies (Rosa et al., 2017), virtual reality in surgeon training (Papanikolaou et al., 2019), simulation-based learning using manikins in nursing education (Cant & Cooper, 2017), simulation in engineering education (Deshpande & Huang, 2011), and even dynamic simulation games for university management (Barlas & Diker, 2000).

Simulation is one of the most popular methods in HE. During the last 20 years, simulation appeared in the *topic* (article's *title* or *abstract* or *keywords*) of over 1.8 million articles in Web of Science (WoS)—of them, about 100,000 articles were devoted to HE. Simulations can be digital or mathematical or both, physical versus virtual, visual versus interactive, static versus dynamic, web-based versus local simulator, digital game vs. role-playing game. Simulation models are usually computerized; the development of most simulation models was in tandem with the development of the computer and other technological platforms. During the last 10 years, smart phone simulation applications have become popular along with educational gaming, internet-based simulations, and, more recently, the cloud platform for simulation with big data (see the forthcoming special issue of the *Journal of Simulation* devoted to "Modeling and Simulation in the Cloud Computing Era"). Simulation is merely a proxy for a real system; it cannot capture the full capacity of the real system due to the latter's complexity and the lack of information available about the real system. Thus, verification and validation are important. Sometimes the term *simulation* is used loosely in various contexts that are hard to define.

There are review articles on specific simulation methods in HE, as shown in Table 3.2, but no overview of all types of simulation models in HE is found in the scientific literature, to the best of our knowledge. The purpose of this chapter is to remedy this lacuna. The purpose of our study is to classify and present the various types of simulation methods as related to HE and to describe their areas of application and their frequency in the literature.

The closest to our classification is Banks (2009), with the introductory chapter to the book by Sokolowski and Banks (2009) that tries to present an overview on "Principles of Modeling and Simulation: A Multidisciplinary Approach" (ibid.). The article by Banks (2009) is on simulation models in general, not necessarily on HE, and is directed at graduate students, who have an analytic background, to be trained as builders of models and simulation. In contrast, our chapter is directed at HE management and researchers who do not have an analytic orientation. Banks (2009) classifies modeling and simulation into two types: (1) *Stand-alone simulations.* These are grouped into five categories: training, decision support, understanding, education and learning, and entertainment. (2) *Integrated simulation.* The criterion for this classification is "whether or not the simulation program runs independently from the system it represents" (ibid.).

The approach to classification in our overview is somewhat different. We first classify the various simulation methods and their areas of applications in HE; second, we give examples of articles on these methods in HE; and third, we count the frequency of appearance of the various simulation methods in the scientific literature in the context of HE.

We identify, in this overview, two main types of simulation models in HE:

1. ***Analytic simulations*** are subdivided into several methods: *(a) System dynamics, (b) Discrete-event simulation and Monte Carlo, (c) Agent-based simulation, (d) Deterministic simulation.*
2. ***Educational simulations*** are subdivided into several methods*: (a) Virtual, (b) Games, (c) Simulators, (d) Box trainer, (e) Manikins.*

Analytic simulations models (Yang, 2014) consist of mathematical equations or a series of relations between various components, be they deterministic vs. stochastic, discrete vs. continuous, or static vs. dynamic. An analytic simulation model in HE usually allows management to plan their affairs, to conduct virtual experiments, or to test policies and system behavior under various scenarios—answering "what if" questions regarding enrollments, income, costs, etc. (e.g., Zaini et al., 2017). Evidently, *educational simulations* in HE are much more popular than *analytic simulation* models and tools (Vlachopoulos & Makri, 2017).

This is not a comprehensive review of all simulation publications in HE, since there are too many such articles. Thus, this review provides a wide range of simulation methods applied in HE, classified by type, with examples that give some idea of the specific areas of HE they are used for and the level of HE hierarchy to which they are applied. Articles of literature review for specific simulation methods or areas of application are reported wherever possible. The examples are taken mainly from journal papers, mostly from the last two decades (from Google scholar). Moreover, taxonomy tables summarize the number of articles published for each simulation method in HE in WoS and the areas of applications they are used for in HE.

This overview is useful for administrators in HE institutions, including heads of departments, deans, consultants, and presidents, to apprise them of the growing use of simulations in HE and the advantages and disadvantages of their potential use in HE.

Section 3.2 of this chapter is devoted to *analytic simulation* methods in HE. Following that, Sect. 3.3 covers the main *educational simulation* methods. Section 3.4 provides the number of articles on simulation methods in each of these two groups and their areas of application in HE during 2000–2019. Finally, Sect. 3.5 concludes the chapter.

3.2 Analytic Simulations for Managerial Planning in HE

Analytic simulation models consist of mathematical equations or series of logical relations between various components, be they deterministic vs. stochastic, static vs. dynamic. Analytic simulation models in HE allow management to plan their affairs, to conduct virtual experiments, or to test policies and system behavior under various scenarios—answering "what if" questions regarding enrollments, income, costs, etc. In the Encyclopedia of Business Analytics and Optimization, Yang (2014) categorizes analytic simulation models into three types: system dynamics, discreet event simulation, and agent-based simulation or model. Brailsford et al. (2019) also used the same three simulation models in the context of operations research. These three models are digital models with commercial software—for example, AnyLogic supports all three models (ibid.) and simulation in R (Hallgren, 2013). We also added here subcategory Monte Carlo simulations which often appear with stochastic simulations as discrete-event simulation or agent-based simulation. Historically, the term simulation had been used loosely in the context of HE planning; thus, a fourth category can be devoted to those various mathematical deterministic static analytic simulations. In this section, the analytic simulation methods are presented:

(a) System dynamic (SD)
(b) Discrete-event simulation (DES) and Monte Carlo
(c) Agent-based simulation or model (ABS or ABM)
(d) Deterministic and other Analytic Simulation Models

As summarized in Appendix 2, in HE, all these simulation methodologies were used by management, mainly for planning in all the levels of HE: department, college, university, national, and international. There are other ways of classifying these analytic simulations such as, stochastic (Monte Carlo) versus deterministic simulation and discrete time versus continuous simulation. However, the classification we used here is the most common. In addition to the type of model, our taxonomy includes the area of application in HE, the level of the organization where the model was used, and the country of application (wherever relevant). We tried to cover a large variety of countries. In HE, all these three simulation methods were used by management mainly for planning efficiency and quality evaluation, strategy, forecasting, and resource allocation, as detailed in Appendix 2, which is organized in chronological order of the articles. The four analytic simulations are described in the following four subsections.

3.2.1 System Dynamic (SD)

SD was developed originally for industrial applications—termed originally *Industrial Dynamics* by its initiator, Forrester (1961). SD is based on a set of differential equations describing the relevant system as based on stock, flow, and feedback in each subsystem and the relationships among them. This is a deterministic continuous-time system, where rather than individual entities, a continuous flow of entities is moving in the subsystems. SD model consists of a set of differential equations which represent non-linear systems. An example of a computer package is STELLA (Richmond, 2004). STELLA is short for Systems Thinking, Experimental Learning Laboratory with Animation [also marketed as iThink since 1986]. The advantage of SD is that it is a non-linear model, which describes the interrelationships among various subsystems within a large system which are captured dynamically over time.

Already in Thompson, 1970, Thompson suggested the use of Industrial Dynamic simulation, where the model conceptualizes the HE institution as a system of interacting flows of students, faculty, capital assets, information, and money—the flows are continuous over time. By the late 1980s, White (1987) reported that Simulation is one of the most reported OR methodologies used in HE—third in frequency, with 24 out of 146 articles. However, White states that *"*many of the large-scale simulation models for financial planning have fallen into disuse.*"* Nevertheless, 15 years later, Bell et al. (2012) highlighted SD as the most useful hardcore OR methodology used in HE. Thus, in their book, they devoted two chapters to SD approaches (chapter 11 by Galbraith, 2012; and chapter 8 by Voyer et al., 2012) while none to other types of simulation. Kennedy (2008) performed a taxonomy of SD educational policy. Later, Kennedy (2011) reviewed forty SD papers on HE (two more in K-12 education) and produced a taxonomy of SD models of educational pedagogic issues that were published during the period 2000–2010. His taxonomy was performed along two dimensions: five "hierarchical levels," and seven "areas of concern" in HE. In the hierarchical HE level dimension, most of the papers were devoted to university wide management issues. In the largest group in the "areas of concern" the papers were devoted to planning, resourcing, and budgeting. We identify in a WoS search that 2432 SD articles are applied to HE; namely, HE and SD appear in their topic (title or abstract or keywords), of which for 99 articles HE and SD appeared the articles' title. Here are some examples of applications of SD in HE, as summarized in Appendix 2 in chronological order.

Voyer et al. (2012) used the SD approach to improve an advising system for Business School undergraduates in the USA. Based on a survey of graduating seniors, advising services received low marks. With the school team, four key variables were identified for the main four subgroups: Advisors (total workload, advising workload, time spent with students, etc.); students (wait time, queue length, student satisfaction, etc.); faculty (faculty involvement, the complexity of curriculum, and guidance requirements; other (time frame, automated advising, and budget). The relationships among the key variables were verified to construct SD flowcharts which considered possible external disturbances outside of the Business School. Various policies were tested, and policy recommendations were presented to the management to improve the student advising system: increasing their satisfaction via using automation, simplifying the curriculum, and involving faculty in the advising process in critical periods.

Brailsford and De Silva (2015) used an SD model to plan the better provision of state-funded dental care and the future university intake of dental students in Sri Lanka. The model had two components—the supply and demand for dental services on the national level. The supply component considered the career progression of dentists from recruitment and training at the university through various career paths through retirement via SD. The demand component calculated various scenarios for the national future dental care, based on the potential future economic development of Sri Lanka.

Kara (2015) used a simple SD nonlinear stochastic model for the provision of HE service in Turkey on the national level during a global economic crisis. Two main assumptions were used: the quality performance was rising stochastically but modestly, and the increase in the technology level leads to improved employment perception and higher levels of employment. The demand and supply nonlinear time-dependent equations are estimated (via regression) as a function of HE price, customers' income, service quality, the degree of using technology in HE and expected job placement. The author presents the SD differential equations and the fluctuations of the main two variables over time as a function of the explanatory variables and the budget allocation to HE.

Fateh Rad et al. (2015) investigated the relationship between university and industry in Iran as two major infrastructures of national innovation systems in leading scientific and industrial settings. The relationship between the two systems is captured by SD nonlinear differential equations, based on a joint investment between industry and university, in three levels of communication from the lower to the higher levels.

Strauss and Borenstein (2015) developed their SD model for long-term planning of undergraduate education in Brazil at an aggregate level. As the purpose of the government was to increase undergraduate enrollment, it met with partial success. The scenario analysis considered government regulations/policies, demand, and the balance between the public and private sector.

Dandagi et al. (2016) used a questionnaire with 207 responses to establish causal relationships between factors for strategically governing a technical university in India. Factor analysis was used to generate latent variables, which were utilized to build the structural equations of SD model, for strategic management of the university.

Al Hallak et al. (2017) used SD for student enrollment in the Syrian private HE sector, which examined the dynamic interactions of student flows, staff ratios, and investments in facilities. This was a decision support system that might help to increase enrollments. Various scenarios were examined.

Faham et al. (2017) analyzed the key factors and obstacles related to education for sustainable development in HE. They created a model using SD to develop education for sustainable development in HE, with the emphasis on sustainability competencies of students. The approach of SD helped to recognize the interventional procedures in fostering competencies of students in the university. The model described the dynamic interactions among the students, scientists, content, policy, pedagogy, community, and government. The model was applied to the University of Tehran, Iran.

Ghaffarzadegan et al. (2017) used SD to model the education workforce pipeline on the national level. They introduced two mechanisms that act on the education enterprise, causing the number of educated people to increase dramatically with relatively short-term changes in the job market. Their illustrative dynamic model showed that the system was susceptible to small changes, and they introduced self-driving growth engines that were adequate to over-incentivize degree attainment. Moreover, they showed that the mechanisms magnified the effects of short-term recessions or technological changes and created long-term waves of mismatch between workforce and jobs. The implication of the theory was that degree inflation magnified pressures on those with lower degrees, and increased under-employment, job market mismatch, and inefficiency.

Zaini et al. (2017) reported on a real-life study in a USA university. In response to financial problems, the administration reduced undergraduate tuition, which resulted in an increase in student enrollment. The faculty, who argued that the quality of education had been declining, resisted the expansion. The growth in the number of students also affected the use of the university's infrastructure. The authors developed a simple SD model of university expansion with emphasis on the areas of planning, resourcing, and budgeting.

Kara (2018) was concerned with the mediocre, low productivity, and low-performance levels of many universities in developing countries. He suggested an SD model, where university performance was expressed by teaching quality, and research productivity levels were related to three resources: human capital, social capital, and physical capital. He used structural equations expressing the dynamic behavior of the system over time. The model measured the improvement in quality and productivity of the university as a function of subsidy and reinvestment. The simulation experiments obviated the need for the university to undergo a long and expensive trial and error process.

As shown in Table 3.1, in our search of WoS during 2000–2019, *SD*, in general, appeared in the *topic (*title, abstract, or keywords) of 37,763 articles; the combination *system dynamic and HE* appeared in the *topic* of 2432 articles, and *system dynamic and HE* appeared in the *title* of 99 articles.

Table 3.1 Number of articles on *simulation methods* in general and in higher education[a]

Method Name	Number of articles during 2000–2019			Percentage	
	1. Method in topic	2. Method and HE in topic	3. Method and HE in title	Column (2) from (1)	Column (3) from (1)
1. Simulation	1,834,848	99,026	4223	5.397	0.230
A. Analytic simulations					
2. System dynamic (SD)	37,763	2432	99	6.440	0.262
3. Monte Carlo	225,568	8851	176	3.924	0.078
4. Discrete-event (DES)	69,259	5426	129	7.834	0.186
5.a Agent-based (ABS)	48,772	3502	171	7.180	0.351
5.b Deterministic and others	407	34	0	8.354	0
A. Total of Analytic Sim.	**381,769**	**20,245**	**575**	**5.303**	**0.151**
B. Education simulations					
6. Virtual	261,559	30,390	2650	11.619	1.013
7. Simulator	102,142	9583	449	9.382	0.440
8. Game	188,519	14,878	1447	7.892	0.768
9. Box trainer	316	126	3	39.873	0.949
10. Manikin	3516	963	41	27.389	1.166
Total of Education Sim.	**556,052**	**55,940**	**4590**	**10.060**	**0.825**
Total A + B	**937,821**	**76,185**	**5165**	**8.12**	**0.551**

[a]Assessed from the Web of Science, Oct. 2020. See Appendix 1 on synonyms for HE and each simulation method. Topic includes title, abstract, or keywords. Bold lines are the totals of the groups of simulation methods

3.2.2 Discrete-Event-Simulation (DES) and Monte Carlo

Discrete-event simulation (DES) first emerged in the late 1950s and steadily grew in popularity to become the most frequently used of the classical Operational Research techniques across a range of industries and users. DES models look at the operation of a system as a discrete sequence of events in time, typical of a manufacturing process. Each event occurs at a particular instant in time and marks a change of state in the system. This contrasts with continuous simulation, in which the simulation continuously tracks the system dynamics over time. Conventional DES constructs are entities, activities, and queues; these constructs are linked to form a complex process in which entities flow. Probability functions are also used to model stochastic processes. DES, alternatively termed Activity-Based Simulation or Monte Carlo Simulation (Banks et al., 2005), is the main analytic simulation model used in practice since the 1960s. In DES, the incoming entities stand in queues, and they receive service activities or resources in a station. In some systems, human service becomes part of the activities and resources. DES allows for the randomness of the service time of the service provider within a given probability distribution and randomness of the inter-arrival time between entities all within given probability distributions. The following are some examples of the application of DES in HE.

Schellekens et al. (2010) developed a process-focused, demand-driven operational model for delivering educational programs to support the development of individual students and to provide a flexible alternative for the traditional supply-driven and class-based organization of educational programs. DES was developed and applied to the higher education of professionals in the Netherlands.

Oltean et al. (2017) dealt with facility planning and renovation using DES. The purpose of DES was the viability of the building and maintaining process in a generic public university organization. The events were driven by internal, external, or mixed causes generated randomly. Some of the uncontrollable events occurring in the process may drive the discrete evolution to disturbance rejection states, where specific recovery strategies are applied. If recovery is successful, disturbances may become sources of innovation.

As shown in Table 3.1, in our search of WoS during 2000–2019, *discrete-event*, in general, appeared in the *topic* (title, abstract, or keywords) of 69,259 articles; the combination *discrete-event and HE* appeared in the topic of 5426 articles; *discrete-event and HE* appeared in the *titles* 129 times.

Since most models of DES and ABS are stochastic, using randomness, where the randomness often materializes via sampling like Monte Carlo gambling. Often Monte Carlo appears together with DES and sometimes also with ABS. Thus, it appears in the literature more than DES and ABS combined. Referring to Table 3.1, in our search of WoS during 2000–2019, *Monte Carlo*, in general, appeared in the *topic* (title, abstract, or keywords) of 225,568 articles; the combination *Monte Carlo and HE* appeared in the topic of 8851 articles; *Monte Carlo and HE* appeared in the *titles* of 176 articles. However, the count in the title of the articles shows that *Monte Carlo* is even less than ABS. Monte Carlo simulation without DES or ABS stands for various other analytic stochastic simulation methods.

3.2.3 Agent-Based Simulation (ABS)

Agent-based Simulation (ABS) is a relatively new paradigm that simulates the simultaneous operations and interactions of multiple autonomous agents (determine their own actions) to predict complex processes. The agents can be individuals, groups, or institutions. Agents may behave differently from each other. ABS assesses agents' effects on the system as a whole—it adds behavior (in terms of decision rules) to micro-simulation. Agents' behavior can be adaptive in response to other agents or environmental changes or other agents' behavior; feedback and memory are crucial in ABS. Monte Carlo is utilized to generate randomness. ABS has elements of game theory, complex systems, and multi-agent systems (Yang, 2014). Siebers et al. (2010), who reviewed DES in general (not necessarily in the context of HE), claimed that DES is “dead” while ABS, which replaces it, will stay for a longer period. They state that in the early 1990s, ABS “promised to offer something novel, interesting, and potentially highly applicable to OR. However, there is relatively little evidence that ABS is much used in the OR community, there being few publications relating to its use in OR and OR-related simulation journals.” Indeed, ABS is a more general model than DES, and thus it is more complicated, requiring more data. This makes it more difficult to use, especially in the case of HE administrators. Moreover, not every situation requires ABS, and a basic course in simulation is not likely to include ABS—it is dependent on the instructor and the software chosen for the course. Nevertheless, OR specialists have been using ABS without using this term since the late 1980s. See, for example, Stern and Sinuany-Stern (1989), Sinuany-Stern and Stern (1993), and Sinuany-Stern et al. (1997), where the terms used were behavioral based in DES, within the framework of operations research.

In the literature review of ABS by Gu and Blackmore (2015), they see ABS as a bottom-up model where the macro-level behavior is a result of the micro-level agents and their interactions. In their systematic review of the applications of ABS in HE by area of application, they present thirty-five articles during the period 1997–2013. During the years 1997–2005, the number of articles published was one or none every year. The areas with the maximal number of articles were academic activities (with twelve articles) and teaching and learning (ten articles). Three more areas with four articles each were: student performance, application and enrollment, and university collaboration. They also found ABS applications in the ranking of universities.

Molders et al. (2011) suggested modeling scientists as agents. Base on this idea, Gu et al. (2015) built a hypothetical ABS, where the productivity of the agents (scientists) is measured under several environmental assumptions. Three types of academic agents (scientists) were categorized by their strategy: Careerists who strive for high IF journals, Orthodox who strive for topical fitting factor, and Mass who strive for high acceptance rate journals. The papers are characterized by impact factor, acceptance rate, and topical fitting factor. The simulation has six sub models: (1) Create journal, (2) Create academics, (3) Academics move around, (4) Academics submit papers, (5) Journals publish papers, (6) Retire and recruit academics. The number of journals and total number of acceptable papers stayed the same in all scenarios. This was a competitive environment where the composition of each group of academics changed over the scenarios. The results showed that the Orthodox type has the most consistent achievements.

Tan et al. (2019) built a discrete-timed stochastic simulation model based on parallel systems to explore the relation between the number of submissions and the overall standard of academic journals within a similar discipline under peer review. The model simulates the submission, review, and acceptance behaviors of academic journals in a distributed manner. The results point to the possibility that the standard of academic journals deteriorates due to excessive submissions. Over twelve articles are cited on this issue using ABS, including a review of the literature on the use of ABS in scientific publication and the peer-review system by Kovanis et al. (2016).

As shown in Table 3.1, in our search of WoS during 2000–2019, *agent-based*, in general, appeared in the *topic* (title, abstract, or keywords) of 48,772 articles; the combination *agent-based and HE* appeared in the *topic* of 3502 articles; *agent-based and HE* appeared in the *titles* of 171 articles.

3.2.4 Deterministic and Other Analytic Simulation Models

Already in 1967, Weathersby applied a linear regression simulation model to predict costs of academic departments in the University of California, Berkeley. Cost simulation is defined as a collection of mathematical expressions that attempt to interrelate analytically; these are the costs and input parameters of HE institutions. Hopkins (1971) called such mathematical models deterministic simulation models. Some of them are large scale for university planning. Hopkins raised questions about their large expense and accuracy. Often the models are not well understood by HE administrators, and they require major data collection. Sinuany-Stern (1983) illustrated the general structure of a cost simulation model for university planning (Fig. 2 and Fig. 4; p. 212, 214, ibid.) utilizing a set of equations where some led to others.

Larson et al. (2014) claim that there were too many PhD graduates, i.e., too few academic job openings. They used a demographic model, utilizing a basic reproductive number R_0—the mean number of new PhDs that a typical tenure-track faculty member will advise during his career. The model calculated that in the then current situation, $R_0 = 1$ was sufficient to secure tenure track positions for all PhD graduates, but in a situation of regional population growth, a higher value was needed $R_0 > 1$. Applying the model to MIT data in 2011, the R_0 average in engineering was 7.8, which was too high. Some fields had a reproductive value $R_0 < 1$, which indicated a severe shortage of PhDs in the future (e.g., mechanical engineering). However, another field had $R_0 = 19$ (environmental engineering). The authors suggested that the intake of PhD students by disciplines could be improved by also considering the industry demand for PhDs in areas such as STEM and by raising the level of master's degree graduates, which may replace the access demand for PhDs by industry.

Siniksaran and Satman (2020) designed a simulation software, "World Universities Ranking Simulator" (WURS), for the three popular world university rankings: THE, QS, and ARWU. The purpose of the simulator was to enable the institution to detect the parameters they need to improve in order to raise their scores in these three rankings. The data needed was outlined, and the transformations and manipulations performed by the simulator were detailed.

3.2.5 Combining Analytic Simulation with OR and Other Methods

Simulation is one of the most popular methods in HE and in operations research in general. Yang (2014) stated about analytic simulation methods (i.e., SD, DES, and ABS): "In OR context, simulation is often used as part of business optimization to understand the impact of changes" and is used sometimes to improve the system. As a future direction, Brailsford et al. (2019), in their general review of simulation, suggested using a hybrid of some of the above-listed simulation methods with each other and with other OR methodologies, such as optimization. They pointed at AnyLogic software as the most used simulation software, which accommodates the three types of analytic digital simulations: SD, DES, and ABS.

Below are some HE applications which combine simulation with other OR methods.

Barlas and Diker (2000) developed an interactive dynamic simulation model into a university management game, UNIGMAE, based on SD. They generated numerous performance measures and demonstrated the systemic nature of university management. This game enabled stakeholders to understand those individual decisions, in isolation, yield counterintuitive results when not coordinated with related decisions. Sinuany-Stern (1978) combined deterministic simulation for cost prediction with optimization for budget planning in a multi-campus community college.

Hussein and El-Nasr (2013) used SD simulation to understand the relationships among various design factors of an HE quality model. The TQM (total quality management) approach was used, where eleven main factors affecting quality were identified: building, facilities, courses, marketing, counseling, library and information centers, student services, legalism and morals, scientific evaluation, staff level, and management. The institutional budget can be allocated proportionally to the weights given to each factor by management. However, an optimization model utilizing a *genetic algorithm* was suggested to achieve an optimal budget allocation of the SD model to maximize the quality of the HE institution. NetLogo software was used (https://ccl.northwestern.edu/netlogo/).

3.3 Educational Simulation in Higher Education (HE)

There are additional special types of simulations, educational simulations, specific to pedagogy in HE, which are used much more often than the analytic simulations mentioned in Sect. 3.2. These *educational simulations* include: serious games, video games, computerized and non-computerized simulators, physical simulators, virtual worlds, and massive multi-player online games—most are digital, internet bases, and computerized—and all are used for teaching and training in HE (Bradley, 2006). We classify *educational simulations* into five main methods:

1. Virtual
2. Simulator
3. Game
4. Box trainer
5. Manikin

"Simulation and gaming" sometimes is used as a general term for educational simulation. Simulation in the pedagogy of HE is spreading with the evolution of computer technologies and internet-based communications. These pedagogical tools and computer-based simulations, and serious games enrich the learning and practical training in many disciplines.

Since there are too many articles on *educational simulation* (4590 articles vs. 575 for analytic simulation, as shown in Table 3.1), Table 3.2 and our overview contain mainly review articles in this section, while covering these five methods. Sometimes the terminology of the five methods is fuzzy; thus we divided Sect. 3.3 into two main parts: Sect. 3.3.1 is devoted to the five educational simulation methods, while Sect. 3.3.2 is classified by academic disciplines.

3.3.1 Educational Simulation by Method

3.3.1.1 Virtual Learning

Virtual simulation enables 3-dimensional environments and objects to look real when transmitted, which creates for the student an immersive and engaging learning experience. A virtual Lab allows the student to perform experiments virtually, saving materials, reducing cost, increasing safety, and enhancing accessibility, especially in STEM disciplines. Virtual simulations are often used for training in various medical fields such as nursing, surgery, radiotherapy, midwife training, radiation therapy, and pharmacy education. The main advantage of using virtual simulations is the ability of the trainees to repeat the procedure tasks several times. For instance, in the field of surgery, the possibility to repeat a certain surgical procedure enhances the muscle memory ability by internalizing effective feedback within its virtual platform (Papanikolaou et al., 2019). For example, the Moog Simodont dental trainer is Virtual reality (VR) based platform which was introduced within the pre-clinical studies and was examined in a study within an operative density restoration course for undergraduate students (see Murbay et al., 2020). Manual and digital methods were included to evaluate the students' performance. It was found that the students who were exposed to the Moog Simodont were evaluated significantly higher with performance and preparation (manually and digitally). These findings support and strengthen the claim that this virtual reality simulator is essential to improve dentist student's skills and contributes to such kind of undergraduate restoration course (ibid.).

Table 3.2 Review of articles on educational simulation in higher education

Author (year)	HE area reviewed	Years covered	Type of simulation	No. of Articles reviewed	Type of review[a]
Faria et al. (2009)	Business	1970–2009	Business games	304	All[b]
McGaghie et al. (2010)	Simulation-based medical Edu. (SBME)	2003–2009	All medical simulations	64 selected articles	Compared to 3 reviews from 1969–2003
Cant and Cooper (2010)	Nurse education	1999–2009	Manikin	12	NSR
Deshpande and Huang (2011)	Engineering Edu.	1960–2006	Computer game simulation	70	SR
Kennedy (2011)	Pedagogic	1972–2008	System dynamic	40	SR
Cooper and Fox-Young (2012)	Midwifery Edu.	2000–2010	Actor, manikin and virtual	24	SR
Smithson et al. (2015)	Pharmacy	2000–2013	Standardized patient	27	SR
Warren et al. (2016)	Nurse Edu.	2007–2014	Manikin	10	SR
Doolen et al. (2016)	Nurse graduate Edu.	2009–2015	High-fidelity simulation	7 of 34 reviews	Umbrella SR
Sun et al. (2017)	Airway management Edu.	Until 2016	Virtual, comp. Software or manikin	17	SR meta-analysis
Adib-Hajbaghery and Sharifi (2017)	Nurse research Edu.	1975–2015	Manikin	16	SR
Vlachopoulos and Makri (2017)	Across academic fields	2010–2016	Game	123	SR
Cant and Cooper (2017)	Nurse Edu.	2010–2015	Manikin	25reviews	Umbrella SR
Rosa et al. (2017)	Business	1970–2016	Business game	157	SR
Frank et al. (2018)	Surgery arthroscopic	1999–2016	Simulator	57	SR meta-analysis
Horsley et al. (2018)	Nursing research interprofessional	2010–2016	Nursing simulation	48	SR
Kane (2018)	Radiation therapy Edu.	2000–2018	Virtual	40	NR
Papanikolaou et al. (2019)	Surgeons	Until 2018	Box trainer	50	NR comparative
Foronda et al. (2020)	Nursing education	1996–2018	Virtual simulation	80	SR

[a]SR—Systematic Review. NR—Narrative Review, NSR—Narrative Systematic Review
[b]The authors reviewed all articles of one journal "Simulation and Gaming" since its inception in 1970

As shown in Table 3.1, in our search of WoS during 2000–2019, *virtual* in general appeared in the *topic* (title, abstract, or keywords) of 261,559 articles; the combination *virtual* and *HE* appeared in the *topic* of 30,390 articles; *virtual and HE* appeared in the *titles* of 2650 articles.

3.3.1.2 Simulator

A simulator is a device that allows the person to train in an environment like the real one, such as a driving simulator (e.g., car or airplane) for training or practice driving under various conditions. Simulators are also used in medical training. For example, Frank et al. (2018) reviewed 57 articles on the use of arthroscopic simulators for training surgeons to perform joint surgery. In the first level, the improvement in diagnostic arthroscopic operation was noticeable within the simulator itself. In the next stage, a correlation was observed between basic diagnostic arthroscopy and standard of practice. Finally, limited findings indicate that when basic diagnostic arthroscopy procedure is applied in patients, as a continuation of simulator training, it is much more improved and successful (ibid.). The advantages of the simulator include increased safety for patients, a reduction in the time needed for "hands-on" learning by surgeons on the real system (patients in this case), and improvement in diagnostic capabilities.

As shown in Table 3.1, in our search of WoS during 2000–2019, *simulator*, in general, appeared in the *topic* (title, abstract, or keywords) of 102,142 articles; the combination *simulator* and *HE* appeared in the *topic* of 9583 articles, and simulator *and HE* appeared in the *titles* of 449 articles.

3.3.1.3 Games

A simulation game presents students with real-life scenarios relevant to their discipline. Usually, it is competitive, involves several players or groups of players, and is computerized. The game simulation provides the players (students) with rules, strategies, and chances of events to happen, all of which develop students' skills. Juan and Loch (2017) claimed that innovative, serious games and simulations in the pedagogy of HE are spreading with the evolution of computer technologies and internet-based communications. They stated that the use of games and simulation in HE is still in its early stage. Nevertheless, it is just a question of time until such games will gain widespread acceptance. They reviewed five articles that appear in a collection devoted to games and simulations in HE (ibid.). One of these articles is by Vlachopoulos and Makri (2017), who lump together the terms "game" and "simulation," listing the following types of games/simulations in HE: educational games, digital game-based learning, applied games, interactive exercises, and next-generation video and simulation games (games modeled after natural or man-made systems or phenomena, in which players must achieve pre-specified goals). The delivery of games and simulations can be via computer, web browser, consoles, mobile phones, and other mobile gaming devices. These games include serious games, as well as game-based learning in various academic disciplines. The learning goals of the game/simulation can include knowledge acquisition and understanding, increased motivation, engagement, and skill acquisition. The technique can be described as single/multi player, linear/nonlinear, collaborative, competitive, persuasive, synchronous, or immersive. They performed a systematic review of games and simulations in HE, reviewing 123 articles between 2010 and 2016. When the breakdown of the articles was by discipline, business/management led with 21 of the 123 articles; next was health sciences (16 articles), and then computer science (11 articles). Interestingly, 25 of the articles were devoted to Meta-Analysis and Systematic Reviews (ibid.). The results indicated that games and simulations were effective and had a positive impact on cognitive and behavioral learning goals. They concluded that the use of gamified mobile apps and virtual learning (e.g., a student game to practice a business negotiation) increased student engagement, retention, and academic achievements (ibid.).

As shown in Table 3.1, in our search of WoS during 2000–2019, *game*, in general, appeared in the *topic* (title, abstract, or keywords) of 188,519 articles; the combination *game and HE* appeared in the *topic* of 14,878 articles; the combination *game and HE* appeared in the *titles* of 1447 *articles*.

3.3.1.4 Box Trainer

Box trainer is a specific tool designed for laparoscopic surgery that replaces invasive surgeries, thus minimizing cuts of body tissues. Consequently, it is almost impossible for surgeons to have a 3-dimensional view of the operating area. This means more training is required for surgery students. The box trainer is a specific tool with three-dimensional graphics and the use of motion sensors for realistic movements (motion control) to simulate the real situation. Papanikolaou et al. (2019) published a narrative comparative review focused on box trainers and virtual reality simulators. Their review went up to 2018 and covered about fifty articles. Surgical training with box trainers conferred a significant benefit in terms of surgical skills development, increased patient safety, and overall cost reduction even though the use of virtual reality simulators was significantly more expensive. They concluded that simulation training allowed trainees to learn from their mistakes, to repeat surgical tasks multiple times, to establish muscle memory, and to enhance skill competency with the aid of informative feedback.

An example of laparoscopy box trainer type for training basic laparoscopy skills is a "Portable Ergo-Lap Simulator" (which was designed by Dong juan Xiao, within the industrial design engineering in Delft University of Technology, the Netherlands www.tudelft.nl/en/ide/research/research-labs/applied-labs/laparoscopy-box-trainer/). The main aim of this simulator is to help medical staff to improve their proficiency under ergonomic conditions, and its tasks are based on scientific research regarding laparoscopy necessary and relevant skills in this field, as well as feedback of sixty surgical participants after they carried out tasks on the prototype.

As shown in Table 3.1, in our search of WoS during 2000–2019, *box trainer*, in general, appeared in the *topic* (title, abstract, or keywords) of 316 articles; the combination *box trainer and HE* appeared in the *topic* of 126 articles; *game and HE* appeared in the *titles* of 3 articles.

3.3.1.5 Manikin

Manikin is an example of a physical simulator used in nursing education. The use of manikins is associated with reduced costs, increased efficiency in performing certain tasks, and above all, with safety. For example, Lapkin and Levett-Jones (2011) performed a cost-utility analysis to compare medium vs. high-fidelity human patient simulation manikins in nursing education. They used multi-attribute utility function and calculated the costs associated with each of the two alternatives. The conclusion was that medium-fidelity manikins are much more cost-effective than high-fidelity manikin with the ratio of 1:5.

Another study by Curran et al. (2015) examined a different approach to the differences between low and high-fidelity manikin simulators and was conducted within the neonatal resuscitation program (NRP). This program aimed to improve the skills of physicians and other health care staff regarding newborn resuscitation. Medical students participated in the study and were divided into two groups (low and high-fidelity manikin), and the following variables were examined: integrated skills, satisfaction, confidence, and teamwork. The findings raised that satisfaction and confidence were significantly higher in the high-fidelity manikin simulator group comparing to the low-fidelity manikin (yet no significant difference was found regarding integrated skills as well as teamwork).

As shown in Table 3.1, in our search of WoS during 2000–2019, *manikin*, in general, appeared in the *topic* (title, abstract, or keywords) of 3516 articles; the combination *manikin and HE* appeared in the *topic* of 963 articles; *manikin and HE* appeared in the *titles* of 41 articles.

3.3.2 Educational Simulation by Discipline

In this subsection, we cover some disciplines that use educational simulation. We concentrate here mainly on review articles of educational simulations.

3.3.2.1 Health Disciplines

Bradley (2006) wrote about the history of simulation in medical education and how simulation-based training became a standard for medical education. Simulation-based learning affords opportunities to address multiple domains of learning and performance. Unlike traditional clinical education, simulation-based learning provides learners exposure to events that are rare in the clinical setting too and allows learners to assume leadership roles in emergencies. In the health sciences context, simulation means a suitably analogous situation, using digital, virtual, simulator, or other physical apparatus for student/personnel training in many academic health disciplines. McGaghie et al. (2010) reviewed 64 selected articles on simulation-based medical education (SBME) from 2003–2009 and three review articles from 1969–2003. They discuss twelve features and best practices of SBME that teach the need to know to best utilize SBME, concluding that SBME is a complex service intervention that needs to be planned and practiced with attention to organizational contexts (ibid.). Below are some examples of several health disciplines.

Nursing Education: The main simulation tools in nursing education are those that represent patients, from manikins to virtual Lab. The major concern is the fidelity of this simulation, as Nehring and Lashley (2010) claim in the book they edited, containing twenty chapters by various authors, covering various aspects of high-fidelity in nursing education such as research, setting a patient simulation program, and creating an interdisciplinary simulation center. As shown in Table 3.2 there are many literature reviews on nursing simulations (Cant & Cooper, 2010; Cooper & Fox-Young, 2012; Warren et al. 2016; Horsley et al., 2018; and Foronda et al., 2020). Cant and Cooper (2010) reviewed twelve articles on simulation in nursing education (1999–2009), concluding that further exploration is needed to determine the effect of team size on learning and to develop a universal method of outcome measurement. Warren et al. (2016) reviewed ten articles (2007–2014) on the effectiveness of simulation-based education on satisfaction and learning outcomes in nurse practitioner programs, concluding that high fidelity simulation increases students' knowledge and confidence. Adib-Hajbaghery and Sharifi (2017) reviewed sixteen articles (1975–2015) about the effect of simulation training on the development of nurses' and nursing students' critical thinking, concluding that more studies with careful designs are needed to produce more credible evidence on the effectiveness of simulation on critical thinking.

Review of reviews (umbrella review) was performed by Doolen et al. (2016), who reviewed thirty-four review articles on high—fidelity simulation in undergraduate nursing education. They found that only seven articles met some inclusion criteria. They conclude that faculty do not receive enough support in using the simulation. Furthermore, there are great differences among the reviews and the studies, which limit the findings (ibid.). Cant and Cooper (2017) used also applied an umbrella review of twenty-five systematic reviews (2010–2015), covering 700 studies on simulation-based learning in undergraduate nurse education. They concluded that, although most reflect strong satisfaction with simulation education, there are still some gaps in comparable design of the reviews.

Eighty articles on virtual simulations (published during 1996–2018) were reviewed by Foronda et al. (2020) systematically via meta-analysis. They found that most of the articles (86%) pointed at the effectiveness of virtual simulation in nursing education. They conclude that there is a need to improve the research design (ibid.). Horsley et al. (2018) reviewed 48 articles (published during 2010–2016) on interprofessional health care teams in nursing education. Their findings show that collaborative health care in nurse education increased safety and quality of patients' care and satisfaction and reduced health care cost.

In HE, there is a crucial advantage for using virtual reality simulations to achieve improvement in practical skills. For example, to examine the process of medication administration, a study was performed to evaluate the effectiveness of Pharmacology Inter-Leaved Learning Virtual Reality (PILL-VR) simulation in nursing students versus traditional methods (see Dubovi et al., 2017). The students were divided into two groups: one learned with regular lecture-based curriculum, while the other used the platform of PILL-VR simulation platform. A higher significant achievement in knowledge learning (conceptual as well as procedural) were obtained in learning activities with the assistance of the PILL-VR simulation (ibid.).

Airway Management Education: Airway management is often life-saving procedure for patients in acute situations. Sun et al. (2017) reviewed seventeen articles (until 2016) on simulation in airway management education, using meta-analysis to compare simulation-based training for airway management (virtual, computer software, or manikin) versus non-simulation-based training methods. They recommended combining the two methods.

In the field of nursing, methods for training in difficult airway management are not common in study courses. A Virtual Reality (VR) airway intervention is presented and examined within a pilot study to teach difficult airway management (Samosorn et al., 2020). According to the findings, the VR airway Lab was rated high by students and faculty regarding different indices such as improving knowledge in the field of airway management.

Midwifery Education: Like the situation in nursing, patient simulation practices can be defined as the substitution of a bona fide patient encounter with artificial models or manikins, virtual reality, or live actors enacting a scenario that replicates substantial aspects of the real experience in a controlled, safe environment for midwifery.

Cooper and Fox-Young (2012) reviewed twenty-four articles (2000–2010) on simulation-based learning in midwife education, utilizing various simulation methods/tools (e.g., actors, manikin, virtual), concluding that simulated learning of midwifery skills is beneficial, though the clinical practice is still needed. Articles with evidence from obstetrics, neonatology, technical and non-technical skills (teamwork) were included.

A pilot evaluation was performed at the Queensland University by Downer et al. (2020). The use of 3D midwifery visualization resources (3DMVR) by midwifery students was evaluated. The traditional methods (such as books, lectures, and clinical skills in Lab sessions) were available to the midwifery students in addition to the 3D tool. The aim was to evaluate if the 3D tool enhances the students' conceptual understanding of the processes related to birth. According to the results, all midwifery students expressed that the 3D experience was beneficial. The participating students were satisfied with the tool and indicated that the experience allowed an improved and deep understanding of the anatomical and physiological aspects of the process.

Pharmacy Education: Smithson et al. (2015) reviewed twenty-seven articles on standardized patients in pharmacy education, concluding that gaps in knowledge around transferability, scalability, and cost benefit of this technique still exist, and there is a need for pharmacy educators to address these gaps to justify this resource-intensive teaching method. Virtual reality technology provides an immersive and interactive learning environment for pharmacy students as they provide service to patients. Coyne et al. (2019) provided an updated overview of virtual reality in pharmacy education.

Cheesman et al. reported on their experiment on the effective use of Virtual Laboratory Practical Class (VLPC). They took two groups of second-year pharmacology students. One group had access to the VLPC before their Lab session, and the second group had access to the VLPC after their Lab session. The results showed that the first group performed better—with a lower mean completion time compared to the second group. Moreover, the first group reported an increase in their confidence in successfully completing the live practical Lab experiment. They conclude that attending VLPC before the live practical Lab is more effective than attending VLPC after the live practical Lab.

Radiation Therapy Education: Kane (2018) wrote a systematic narrative review of about forty articles on simulation-based education, mainly in virtual environment radiation therapy (VERT) education during 2000–2018. He concludes that: "The evidence suggests that future inquiry involving VERT should explore different ways in which VERT can be used to contribute to the skillset required by the radiation therapist of tomorrow" (ibid.).

3.3.2.2 Simulations in Business Management

Vlachopoulos and Makri (2017), in their review of simulation and gaming in HE, in general, reported that out of 123 articles they reviewed, business management/marketing had the largest number of articles (21); the rest of the articles were devoted to various other disciplines.

Faria et al. (2009) wrote a review of the history of business gaming covering one specific journal, *Simulation and Gaming,* where 304 articles were devoted to some aspects of business games out of 1115 published in that journal during 1970–2009, representing 27.3% of *Simulation and Gaming* total publications. In HE, business games started in a university course in the USA (University of Washington, 1957). Since 1962, business games development stages were tied to computer development: first on mainframes and then growing in complexity until 1984, when PC-based games were developed. Since 1998 internet-based business games were introduced and used in HE. The five main topics that appeared in the literature of business games over the years were: experience gained, strategy aspects of the game, decision-making experience gained, learning outcomes provided, and teamwork experience provided by business games. Since the turn of the millennium, games focusing on specific areas were more common. Examples include games related to marketing, accounting, stock market and finance, and human resource management. Some of the games allowed the use of analytical tools such as forecasting.

For example, Rosa et al. (2017) performed a systematic review of 157 articles on business games during 1970–2016 to analyze the relationship between games and the development of creative potential in business games. They found that business games were not used specifically to promote creativity. Nevertheless, some other related themes were reviewed, such as cognitive and behavioral aspects (ibid.). Business games are often digital and involve several participants in a competitive situation. Sometimes the term gamification was used. Another example is Avramenko (2012) which referred to enhancing students' employability through business simulation.

Computerized Simulation Games for Software IT Project Management: Lui et al. (2015) designed an improved simulation game to train a group of students to take the role of project managers, where the objective was to complete a software design project on time, while adhering to the requirements of the stakeholders, and staying within a limited budget. The players were able to monitor the progress and the effects of their decisions. This design attempted to improve on various elements in other such games existing at the time.

3.3.2.3 STEM Disciplines

For STEM (science, technology, engineering, and mathematics), there are various types of simulations, specific for each discipline and dealing with education and/or research, and sometimes as developers of new simulations. The most frequent use of educational simulations for STEM education is for virtual laboratories.

Alkhaldi et al. (2016) reviewed eleven articles on the implementations of virtual and remote laboratories in various STEM disciplines. Among the Labs in this review Labs were those in physics, biology, chemistry, computer science, information technology, robotics, and mechanical engineering. The advantages of such Labs were summarized as follows: accessibility and flexibility from anywhere at any time, the ability to fit individual pace and schedule, the retrial of experiments without wasting resources, and safe environment. These simulation Labs were often online or cloud based. It was suggested that integrating physical Labs with virtual Labs in creative way would enrich learning.

Deshpande and Huang (2011) studied the state of the art of computer game simulation, where active multi-sensory experiential learning methodologies were used in engineering education. Their review covered the period 1960–2006 and included seventy articles. They reviewed simulation games applications in engineering education in the following eighteen engineering areas (and subareas): civil engineering, electrical engineering (including digital signal processing and power electronics), computer engineering (digital logic, security, protocols, software engineering, information systems, and artificial intelligence), chemical engineering, mechanical engineering (including Engineering, graphics, mechanics, thermodynamics and system dynamics), industrial engineering (including enterprise resource planning, production planning and control and supply chain management) and environmental engineering. In their table of simulation games, they refer to about seventy games in various areas, in addition to engineering, such as business, medical, health, architecture, and physics. They conclude that proper application of simulation games in engineering education would maximize the student's transferability of academic knowledge to industry.

Another example, in the field of developmental biology, a neurosphere simulator became into use during the limitations of the COVID-19 pandemic via online, because of movement from "face to face" Lab classes into an online teaching era (Zupanc et al., 2021). This simulator was developed based on cellular automata models of neurosphere growth and is freely available for students on the web (http://neurosphere.cos.northeastern.edu/). The simulator allows students to experiment with different components of the biological processes which were expressed in the computerized model during this Lab class exercise online, and to download data for further specific analysis, as well (ibid.).

City Planning education: Minnery and Searle (2013) presented an innovative way of using a toy computer game of a city (SimCity 4) in student assignments to develop urban and strategic plans.

In summary, the use of simulation and games in the pedagogy of HE has been growing over the years. For the most part, students were satisfied, though faculty support was sometimes insufficient. Cost effectiveness was usually justified, but not always reported. The literature review and umbrella systematic review articles in Table 3.2 reflect the great variability of the studies' purposes and designs, thus comparability is not always evident. The health educational simulations reported most often in the literature were manikins and virtual simulations. STEM educational simulations were mostly for virtual Labs, while business educational simulations were mainly games.

3.4 Counting Articles About *Simulation Methods* and Their *Area of Application* in HE

In Sects. 3.2 and 3.3, only some examples of articles from the literature on simulation in HE are presented due to the huge number of such articles, running between 4223 and 99,026 (based on line # 1 of Table 3.1). To get an idea about the frequency of publications on the various simulation methods and the areas of application, this section provides the relevant enumeration. Section 3.4.1 counts the number of articles on each simulation method in general versus their count in HE (higher education). Section 3.4.2 counts the number of articles on each application *area* in general versus their count in *HE*. Section 3.4.3 presents the number of articles on each simulation *method by area* of application as applied to HE. In all three tables of this section, the count of articles was performed in the Web of Science (WoS) assessed October 2020. In Table 3.1 and Table 3.3, column 1 counts

Table 3.3 Number of articles on *areas of applications* and *simulation* in general and in HE[a]

Areas of applications	Number of articles			Percentage	
	1. Area in topic	2. Area and HE in topic	3. Area and HE in title	Column 2 from 1	Column 3 from 1
1. Transportation	2,687,092	182,392	8431	6.788	0.314
2. Industry	1,535,172	172,676	6993	11.248	0.455
3. Knowledge transfer	224,253	34,688	3886	15.468	1.733
4. Marketing	7,730,644	767,185	43,741	9.924	0.566
5. Projection	274,406	13,867	351	5.053	0.128
6. Enrollment	697,521	353,146	81,184	50.629	11.639
7. Faculty	217,093	123,689	9714	56.975	4.475
8. Teaching	1,803,689	450,020	49,850	24.950	2.764
Total	15,169,870	2,097,663	204,150	13.828	1.346

[a]Assessed from the Web of Science on Oct. 2020. See Appendix 1, on synonyms for "HE" and "areas" of application

the number of articles with methods/area in their *topic*. Topic means that the search word (or one of its synonyms, see Appendix 1 for the synonyms for each search word) appears either in the *title*, abstract, or keywords of the article. Column 2 counts the number of articles with HE and method/area in their *topic*. Column 3 counts the number of articles with HE and method/area in their *title*. Obviously, for each method, column 2 articles are included in column 1 articles, and column 3 articles are included in column 2 articles. Thus, the count of column 2 is always less than the count in column 1, and the count of column 3 is less than the count of column 2.

3.4.1 Number of Articles on Simulation Methods

As shown in Table 3.1, the simulation methods were divided into two groups: *analytical simulations* methods listed in Sect. 3.2 and *educational simulation* methods listed in Sect. 3.3, used mainly for pedagogic purposes. *Educational simulations* articles out-number the *analytic simulation* articles, since the former are intended for a wider audience, i.e., those disciplines which do not require as much mathematical proficiency as disciplines where *analytic simulation* is used. Even the authors of educational simulations come from a variety of disciplines, such as health professions and education, in addition to the STEM disciplines.

Obviously, out of ten simulation methods listed in Table 3.1, the method with the highest number of articles in all three columns is the generic method *simulation*. Moreover, *simulation* appears more than all the other nine simulation methods combined. For example, in column 1 in general, there were 1,834,848 articles on *simulation* methods, versus a total of 381,769 for *analytic simulation* and 556,052 for *educational simulation*. Obviously, there are overlaps. For example, in some articles for method 4, *discrete-event*, the word *simulation* is often added, thus such article will be counted twice in the total of *analytic simulation*. Thus, in the last row of Table 3.1, the total count is given without the first row of method 1, *simulation*.

In column 2, where the search words *HE* and the specific simulation *method* appear in the *topic* of the articles, the total number of *analytic* articles is 20,245, while the number of *education* articles is 55,940. However, in column 3, where the search is for *titles* that contain the words *HE* and a specific *method*, the total number of *analytical simulation* articles is 575, while the number of *educational simulation* articles is 4590. This proves that *educational* simulations became very important during the last two decades. About 5% of the *analytical* simulation articles in WoS are in HE, where the search words are in the *topic* (percent of column 2 total from column 1), but 10% of the *educational* simulation articles in WoS are in HE. When the search words are only in the articles' *titles* (column 3 as a percentage of column 1) then the corresponding percent is 0.151% for *analytical* simulation and 0.825% for *educational* simulation.

Of the four *analytical* simulation methods in Table 3.1, *Monte Carlo* is the method with the largest number of articles in the first three columns (176 articles in column 3). There are overlaps between *Mote Carlo* and the other two stochastic *analytic* methods: *discrete-event simulation* and *agent-based simulation*. Nevertheless, each of these stochastic simulation methods alone has more articles than *system dynamics*. Note that the method with the smallest number of articles is *deterministic* in all three columns of Table 3.1.

From the five *educational* simulations, the *virtual* simulation method is leading with the maximal number of articles in the first three columns of Table 3.1—with 261,559 articles, of which 30,390 articles include *HE* in their *topic*, of which 2650 articles include *HE* and *virtual* method in their *title*. The method *game* has the second maximal number of articles in all three columns, and the method *simulator* is the third.

In summary, educational simulations have many more articles than analytical simulation methods. From educational simulations, the leading methods in terms of the number of articles in WoS are as follows in order of frequency: *virtual, game*, and *simulator*. The leading methods of *analytical* simulation are *Monte Carlo*, *discrete-event,* and *agent-based* simulation.

3.4.2 Number of Articles on Application Areas

Table 3.3 presents eight application areas where HE can be applied. The leading application areas, according to the number of articles in general (column 1), were *marketing*, *transportation,* and *teaching*. For *HE* and *area* of application in the *topic* of the articles (column 2), the order of leading application areas is *marketing*, *teaching*, and *enrollment*. For HE and area appearing in the title of the articles (column 3), the order of leading areas of applications is *enrollment, teaching*, and *marketing*. Note that Table 3.3 does not refer to simulation at all.

In summary, the leading application areas in HE are *enrollment, teaching*, and *marketing*. Overall, the number of articles in areas of applications as presented in Table 3.3, which come under the rubric of area in topic in column 1 (about 15 million articles), is much larger than the number of articles by methods in all three columns of Table 3.1 (1.8 million articles).

3.4.3 Number of Articles on Simulation Methods by Application Areas in Higher Education

Table 3.4 presents the number of articles with HE and *simulation method* in an article *title* by *area* of application in their *topic*. The assumption behind this is that most administrators and researchers in HE are likely to use HE and area of application in their title to attract a wider range of readers, and thus they tend to extend the method term to the keywords or abstract.

Table 3.4 Number of articles with HE[a] and area of application[b] by simulation method

	Area[b]:								
	1	2	3	4	5	6	7	8	
Methods	TRNS[b]	IND[b]	KT[b]	MKTG[b]	PROJ[b]	ENRL[b]	FAC[b]	TCH[b]	Total
1. Simulation	540	217	47	977	36	1900	96	1804	5617
2. System dynamic	13	19	6	50	10	15	6	21	140
3. Monte Carlo	19	46	1	83	5	14	13	10	191
4. Discrete- event	17	9	1	61	0	50	11	40	189
5. Agent- based	25	7	2	40	1	13	2	14	104
Sum of methods 2–5	74	81	10	234	16	92	32	85	624
6. Virtual	219	74	42	455	4	1036	66	1003	2899
7. Simulator	48	12	4	85	2	306	10	350	817
8. Game	59	60	32	216	3	770	29	390	1559
9. Box trainer	0	0	0	0	0	7	0	5	12
10. Manikin	0	1	0	4	0	86	2	71	164
Sum of methods 6–10	326	147	78	760	9	2205	107	1819	5451
Total	940	445	135	1971	61	4197	235	3708	11,692
Total w/o simulation	400	228	88	994	25	2297	139	1904	6075

[a]See synonyms used in Appendix 1. HE (higher education) and application area in article *title* and *method* in article *topic*

[b]Abbreviations of areas of applications are: TRNS —transportation, IND—industry KT—knowledge transfer, MKTG—marketing, PROJ—projection, ENRL—enrollment, FAC—faculty, TCH—teaching

The figures in Table 3.4 strengthen the results of Sects. 3.4.1 and 3.4.2 (as reflected in Tables 3.1 and 3.3), although the counting method changed. Again, the leading simulation methods, with the maximal number of articles, are the generic term *simulation,* and then come the three leading *educational* simulations: *virtual*, *game,* and *simulator* (last column of Table 3.4). Again, the leading application areas, in terms of number of articles, are *enrollment, teaching,* and *marketing* (last row of Table 3.4). Within each of the three leading methods: virtual, game, and simulator, the maximal number by area follow the same order holds as the total: enrollment teaching and marketing.

For example, focusing on the generic *simulation* method by application areas in HE (row 1 in Table 3.4), the use of *simulation* for *enrollment* has the maximal number of articles (1900 articles, in row 1 column 6). The area of application with the second largest number of articles by area is *simulation* for *teaching* (1804 articles, in row 1, column 8). The area of application with the third largest of articles is *simulation* for *marketing* (977 articles, in row 1 column 4), the same above order of applications areas (*enrollment, teaching*, and *marketing*) applies for the number of articles of each of the main three simulation methods: *virtual*, *game* and *simulator*—in lines 6, 8, 7, respectively.

Similarly, looking at the last column of Table 3.4 (total) the simulation methods with the maximal number of papers and their orders are *virtual*, *game,* and *simulator* (2899, 1559, and 817, respectively). The same order applied to the three leading application areas: *enrollment, teaching*, and *marketing* (rows 6, 8, 7, respectively).

In the following is a comparison between the *analytic simulation* methods and the *educational simulation* methods:

(a) ***Analytic simulation***—four methods: *Monte-Carlo, discrete-event simulation, system dynamics*, and *agent-based simulation,* with 191, 189, 140, 104 articles, respectively, and 624 articles in total compose only 10.27% of the articles.
(b) ***Educational simulations***—five methods: *virtual, games*, *simulator, manikin, and box trainer,* with 2899, 1559, 817, 164, 12 articles, respectively, and 5471 articles in total compose 89.73% of the articles (out of 6075).

Obviously, the *educational simulation* methods comprise most of the articles in Table 3.4, almost 90%, in the WoS during the period 2000–2020.

Moreover, each of these simulation methods: *virtual, game,* and *simulator*; their areas with the maximal number of articles are the same: *enrollment, teaching,* and *marketing* (as shown in Table 3.4, in the intersect of these three methods and three areas). These nine entries (of *virtual, game, and simulator* methods by *enrollment, teaching, and marketing* areas) compose 4611 (76%) of the articles in Table 3.4, not including the generic method *simulation*. Namely, 12.5% of the entries of Table 3.4 cover 76% of the articles—thus, the Preto rule basically holds true.

As shown in Appendix 1, *marketing* (MKTG) area of application includes the following synonyms: finance, financial, strategy, ..., policy models, ..., planning, budgeting, cost, costing, managerial, management, administration, and administrative. Section 3.2 shows that analytical simulations are used mainly in marketing areas, as listed here. Indeed, we see in Table 3.4 that for each of the four analytic simulation methods, including the sum of the *analytic simulation* methods (line of "Sum of methods 2–5" in Table 3.4), marketing has the highest number of articles, while the *educational simulation* methods achieve their maximum in enrollment and teaching, and marketing is in the third place.

In summary, as seen in Table 3.4, the *educational simulation* methods have by far more articles than *analytical simulation* methods. The educational simulation methods with the largest number of articles are *virtual, game*, and *simulator*. The areas of applications with the maximal number of articles are *enrollment*, *teaching*, and *marketing*. However, the *analytical simulation* methods have the maximal number of articles in the *marketing* area of application as expected, while *enrollment* and *teaching* areas of applications are in the second and third places.

3.5 Summary and Conclusions

Simulation is one of the leading methodology/tool in HE, besides its use in Industry, military, leisure, etc. The number of articles in WoS during the recent years on simulation, in general, is over 1.8 million articles; of which simulation in HE composes about 10%. This chapter provides an overview of simulation in HE: first by classifying the simulation methods in HE by type, second by pointing at areas of application where simulation is used in HE; third by verifying the most used simulation methods and their areas of application in HE. We suggest classifying the simulation methods in HE into two main types of simulation models: a. *analytical simulation* methods and b. educational simulation methods—each is divided into sub-methods.

In summary, we found that *educational simulations* have many more articles than *analytical simulations* (in WoS during 2000–2019). The leading simulation methods (in terms of number of articles) are (1) V*irtual* (2) *Game* and (3) *Simulator*—all three methods are from the *educational simulations* group.

The advantages of *educational* simulation are that they are characterized by safety (e.g., in medicine) and accessibility (virtual Lab); are more economic with respect to training, with less disruption of training than exists in real situations (health system simulations, or business game); have more flexibility in training under various conditions, and enable flexibility in training scheduling.

We consider here eight areas of application of simulation in HE: (1) *transportation* (2) *Industry* (3) *Knowledge transfer* (4) *Marketing* (5) *Projection* (6) *Enrollment* (7) *Faculty* (8) *Teaching* (see synonyms used for each area in Appendix 1). The leading areas of application in HE in terms of number of articles are *(1) enrollment, (2) teaching,* and *(3) Marketing*. Looking at the ten simulation methods by eight areas of application in HE (Table 3.4), the same three simulation methods (*virtual, game*, *and simulator*) are leading within each area of application and mostly in the same above three leading areas of applications (i.e., *enrollment, teaching,* and *marketing*). However, the *analytical simulation* has its maximal number of articles in *marketing*—*enrollment* and *teaching* are the next in the number of articles.

The advantages of analytic simulation are manifold. They do the following: improve the ability to choose from alternatives by easily testing various options, policies, and scenarios without disrupting the real system; diagnose problems in complex situations; accelerate real life processes in time via simulation runs, predicting future development and "what if" behavior of the system; and enable visualizing the system operation.

The main disadvantage of simulation methods, in general, is that simulation is an imitation of the real system. Other disadvantages include the need to train the users and teachers to use the specific simulation model with its technicalities, assumptions, options, applications, and interpretation of the results. Verification and validation of the simulation sometimes are neglected, and sometimes, effectiveness/cost value may be questionable.

This overview is useful for developers of HE simulations and for administrators at all levels of HE institutions, including heads of departments, deans, consultants, and councils for HE at the state level, so they can become aware of the growing use of simulations in HE and their potential use.

For future research, enlarging the synonyms and avoiding double counting will improve the accuracy of the articles' counting results. There is a lack of literature reviews on three of the *analytical simulation* methods: *discrete-event* simulation, *agent-based* simulation in HE, and *deterministic and other* simulations in HE. Finally, there is a need to review the economic viability of the various educational simulation tools (digital and virtual) for HE. The COVID-19 pandemic may increase the utilization of the various simulation tools. It would be interesting to study the change in the use of educational simulation, mainly online and web-based simulations, a year and more after the pandemic will be over. Moreover, it remains to be seen what forms of virtual classroom and the virtual university will evolve (see Almog & Almog, 2020).

Appendix 1: Synonyms for: (a) Higher Education (b) Simulation Method (c) Areas of Application

a. Higher Education:
Higher education: academic, college, university, tertiary education, medical education, nurse, nurses, nursing, pharmacy, undergraduate education, undergraduate, airway management education, medical, engineering, business education, internship, higher professional education
b. Simulation Methods:
1. Simulation: simulating, simulate, simulation-based
2. Industrial dynamic, industrial dynamics, system dynamic, system dynamics, system-dynamic, dynamic simulation
3. Monte Carlo

(continued)

4. Discrete-event: discrete-event, DES
5. Agent-based: agent-based, ABS, ABM
6. Simulator: simulators
7. Game: games
8. Box trainer: box training.
c. Areas of Applications:
1. Transportation: transshipment, assignment, project management, CPM, Gant, PERT, network, networks, location, scheduling, timetabling
2. Industry: logistics, maintenance, reliability, inventory
3. Knowledge transfer: knowledge management, management of knowledge, R&D research and development, patent, patents, industrial park, industrial parks, incubator, incubators, entrepreneurship, entrepreneurial
4. Marketing: finance, financial, strategy, strategic, balanced scorecard, BSC, efficiency, efficient, accounting, investment, revenue management, policy modeling, policy model, policy models, renovation, international, internationalization, planning, budgeting, cost, costing, managerial, management, administration, administrative
5. Projection: projecting, forecasting, forecast
6. Enrollment: student/students
7. Faculty: staff, manpower
8. Teaching: teach, practice, practicing, train, training, pedagogy, pedagogic, practitioner

Appendix 2: Taxonomy of Simulation Models Applied to Higher Education

Authors (year)	Type of simulation[a]	HE area	Levels HE hierarchy	Country of application
Weathersby (1967)	Regression	Costs of departments	University by department	USA, UC Berkeley
Baisuck and Wallace (1970)	DES	Enrollment projection	University and regional	USA
Hopkins (1971)	Deterministic. simulation	University planning	University	USA
Sinuany-Stern (1978)	Simulation and optimization	Budgeting and planning	Community college (CC)	USA (multi campus CC)
Kennedy (2008)	SD	Policy issues	All levels	Review 1975–2005
Schellekens et al. (2010)	DES	Program organization	University	The Netherlands
Kennedy (2011)	SD	Policy and pedagogy	All levels 40 articles	Review 1972–2008

(continued)

Authors (year)	Type of simulation[a]	HE area	Levels HE hierarchy	Country of application
Galbraith (2012)	SD	Various	Various	Methodology
Voyer et al. (2012)	SD	Performance	Business sch.	USA
Hussein and El-Nasr (2013)	SD and genetic algorithm	Budget allocation and quality	Institutional	Methodology NetLogo
Larson et al. (2014)	R0, reproduction number	Supply and demand of Eng. PhDs	National	USA
Brailsford and De Silva (2015)	SD	Supply and demand of dentists	National	Sri Lanka
Gu et al. (2015)	ABS/ABM	Academic activities and teaching	All HE levels 35 articles	Review during 1997–2013
Gu et al. (2015)	ABS prototype in NetLogo	Researchers publications strategy	University by department by researcher	Australia
Kara (2015)	Stochastic SD	Stud. Supply and demand and quality	National	Turkey
Fateh Rad et al. (2015)	SD	Strategic—industry relations	University Regional	Iran
Little (2015)	DES and ABS	Quality improve	University	General
Strauss and Borenstein (2015)	SD Undergrad. enrollment	Long run planning, strategy	National HE pub-lic/private sector	Brazil
Dandagi et al. (2016)	SD and Structural equations	Strategy Question-naire factor anal.	University	India
Oltean et al. (2017)	DES—facility planning	Building viability	Public university	Romania
Al Hallak et al. (2017)	SD—facility & faculty plan	Enrollment Mgmt.	Regional private sector	Syria
Faham et al. (2017)	SD	Strategy	University	Iran

(continued)

Authors (year)	Type of simulation[a]	HE area	Levels HE hierarchy	Country of application
Ghaffarzadegan et al. (2017)	SD—Student quantity vs. quality	Policy Edu. job mismatch	Regional	Methodology
Zaini et al. (2017)	SD	Strategy	University	USA
Kara (2018)	SD—Structural equation	Quality and productivity	University	Turkey
Tan et al. (2019)	Discrete-timed model, Parallel systems	Quality of Peer review process	International	China
Siniksaran and Satman (2020)	Simulation	Universities ranking	Universities	Review

[a]SD—System Dynamics, DES—Discrete-event Simulation, ABS—Agent-Based Simulation also ABM (Agent-Based Model). [b]indicating number of reviewed papers in a review paper

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