The International Journal of Technologies in Learning
ISSN: 2327-0144 (Print), ISSN: 2327-2686 (Online)
Volume 31, Issue 1, 2024
https://doi.org/10.18848/2327-0144/CGP/v31i01/133-161

Original Research

On the Pedagogical Character of (Animated) Pedagogical Agents: A Review of Recent (2009–2022) Research

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Received: 08/08/2023; ***Accepted:*** 01/24/2024; ***Published:*** 04/26/2024

Abstract: Pedagogical agents (PAs), animated or not, have received increased research attention during the last two decades. They constitute a modern and intelligent educational technology that has gained momentum due to the recent pandemic that has greatly affected education. In the framework of e-learning, PAs assume the role of mentors, guides, or facilitators who support learners through their online learning tasks. The current research focuses on the educational and pedagogical aspects of the role and uses of PAs within e-learning environments. Major concerns are the learning theories underlying PA-related educational interventions; the outcomes sought in the cognitive, social/emotional, and metacognitive domains; the evaluation tools employed; and the results measured. In a systematic literature review that covers the last fourteen years, recent published research is analyzed to answer research questions such as the popularity of PAs in teaching and learning; the frequency of PA use across education grades, contexts, and taught subjects; the design (type, form, and communication modalities) of Pas; the learning outcomes sought through the PAs across the various education domains (cognitive, social, metacognitive, affective); the evaluation tools; and the results reported. Although the results reported are predominantly positive, they are not balanced. While the cognitive (knowledge) domain is adequately researched (89% of the works), other educational/pedagogical domains of interest are under-researched: social skills (metacognitive skills) are researched by only 26 percent (18%) of the studies reviewed. Along with a surprising dominance of behaviorism, these are the most striking findings; they point toward new directions for PA research, development, and use.

Keywords: *(Animated) Pedagogical Agents, e-Learning, Educational Intervention, Learning Outcomes, Learning Theory, Behaviorism, Constructivism, Collaborative Learning*

Introduction

Among the various scientific and technological developments that change the present and shape the future of our societies, the last two decades have witnessed an intensive development and use of online learning environments (Moore, Dickson-Deane, and Galyen 2011). The progress made in terms of new methods, techniques, applications, and devices is obvious across practically all disciplines. E-learning exploits the latest scientific and technological advances in order to assume an attractive interface and thus support teaching and learning in the modern era (Ordu 2021). Furthermore, the latest social phenomena that

promoted e-learning as the sole teaching solution for a long period of time and across all education grades have aided e-learning to become a mature and reliable paradigm (Maatuk et al. 2021). Desirable features of e-learning, such as flexibility, cost effectiveness, learner autonomy and control over the learning process, personalized experience, digitization of the learning process, and a certain level of user-friendliness result in increased attractiveness and positive affect (engagement, joy, and fun) on the side of the learner (Picard 1997). Claims that such positive attitudes result in enhanced learning outcomes, however, are yet to be proved by rigorous educational research (Ritonga, Azmi, and Sunarno 2020).

The conventional teacher-centric education method adopted under behavioristic theories of learning has evolved over the years into learner-centric methods such as constructivism, social constructivism, collaborative learning, and problem- or project-based learning. These modern approaches are greatly assisted by online learning, where virtual mentors, peers, and tutors are gaining ground in multiple ways. PAs are software constructs of various types: "Pedagogical agents are lifelike characters presented on a computer screen that guide users through multimedia learning environments" (Heidig and Clarebout 2011). PAs may assume various forms and play their role via a variety of media: they may be human-like, animated or not, or disembodied voices or even text messages that guide, aid, or coach the learner(s) (Davis, Vincent, and Park 2019). PAs reinforce socio-cognitive characteristics of online digital learning, providing empathetic support to the learners' behaviors (Hayes-Roth and Doyle 1998), while learning outcomes are improving when the PA is interacting cognitively with the students/learners (Moreno and Mayer 2007; Schroeder, Adesope, and Gilbert 2013; Johnson and Lester 2016).

The different forms, roles, and designs of the PAs have significant positive impacts on student learning and student behavior (Santoso et al. 2016; Tschannen-Moran, Hoy, and Hoy 1998). In a preliminary study of recent research (Papoutsi and Rangoussi 2020), it was found that the most common choice of researchers is an anthropomorphic, animated, female PA employed in classes of undergraduate students who study Computer Science, with mostly positive (increased) learning outcomes. In these research works, PAs efficiently hold the role of class instructors; they therefore emerge as a promising new class of educators for the (near) future—yet, for online classes only. A major concern that arises along that path is the pedagogical efficiency of these educators as well as their impact on aspects of learning other than cognitive. Indeed, as a look into recent works reveals, a rather small percentage of them investigate whether PAs are indeed pedagogical. Such issues as the kind of experience PAs offer to the learner, their responsiveness to the class climate, attitude, feeling, or behavior, the affective states they elicit in the learner, and the motivation, social, and metacognitive skills they help the learner develop, are mostly overlooked or under-researched. The lack of research attention on the pedagogical qualities of the PA is verified because issues such as (1) the overarching learning theory under which the PA is developed and used in a given research study, (2) the method and tools employed for learner monitoring while he/she is interacting

with the PA and the learning content and for evaluation of the progress made, as well as (3) the learner skills sought and eventually developed beyond learning outcomes, such as social/emotional or metacognitive skills, are hardly present in existing research and practically never documented by concrete results.

The present review aims to address the aforementioned limitations in existing research, document, and quantify them, and eventually answer a set of detailed research questions (RQs). Such a close examination will hopefully reveal interesting new directions for further research and development in the field of PAs and their use in education. Through a systematic literature review methodology and a careful two-stage selection procedure, 121 journal papers are retrieved and analyzed.

In order to define the set of RQs for the present review, a number of existing relevant reviews have been studied and the RQs investigated therein have been compared and summarized (Richards and Dignum 2019; Apoki et al. 2022; Schroeder, Romine, and Craig 2017; Armando, Ochs, and Régner 2022; Azevedo et al. 2022; dos Santos and Netto 2020; Wang et al. 2022; Zhang, Zou, and Cheng 2023). Those deemed meaningful for the present study have been adopted and adapted; they were complemented with novel RQs defined here. RQs are presented here, grouped into two sets, namely,

- RQs of a rather self-evident nature that are common across existing similar works:
  1. How popular has the subject of PAs in education within recent research?
  2. In what education grades does relevant research take place?
  3. In the context of which taught/studied subjects are PAs introduced?
  4. What are the most popular forms/types/communication modalities of PAs?
- RQs focusing on the educational and pedagogical qualities of the PAs:
  5. What is the learning theory underlying educational interventions with PAs?
  6. At what time points/periods are measurements taken for evaluation?
  7. What are the research results on learning outcomes achieved with PAs?
  8. What are the research results on the development of social skills with PAs?
  9. What are the research results on the development of affective skills with PAs?
  10. What are the research results on the development of metacognitive skills with PAs?
  11. What are the research results on the motivation of students by PAs?

Answers to these questions are expected to reveal interesting hidden aspects of the educational functions of PAs incorporated in e-learning platforms, as well as strengths, weaknesses, and gaps in the reviewed literature. Such results are eventually expected to aid and support the design of future research in new, more focused directions.

Methodology of the Systematic Review

Publication Retrieval and Selection Process

The systematic literature review methodology employed in this paper is a modified version of the one proposed for medical research by Pai et al. (2004) combined with the methodology proposed for software engineering by Kitchenham (2004) along the major steps of planning, conducting, and reporting the review. The retrieval and selection processes are presented in Figure 1 according to the PRISMA steps (Moher et al. 2009; Page et al. 2021). Due to its highly technological nature, the reviewed subject is rapidly evolving and expanding; a review is therefore meaningful only as far as it covers the most recent developments. The review covers the last fourteen years (2009–2022), a period that has witnessed considerable growth in this subject. The starting point was set to year 2009 because a number of important reviews adequately cover the preceding decade, two major ones being Moreno and Mayer (2007) and Schroeder, Adesope, and Gilbert (2013); although published in 2013, the latter essentially covers the years up to 2009 to 2010. The bibliographic search was carried out in the Scopus database, a choice that offers certain advantages: it is available online through the academic library services system, it spans a wide spectrum of disciplines, fields, and countries of origin, and it achieves a good balance between the inclusion of articles for wide coverage purposes and the exclusion of articles for quality purposes.

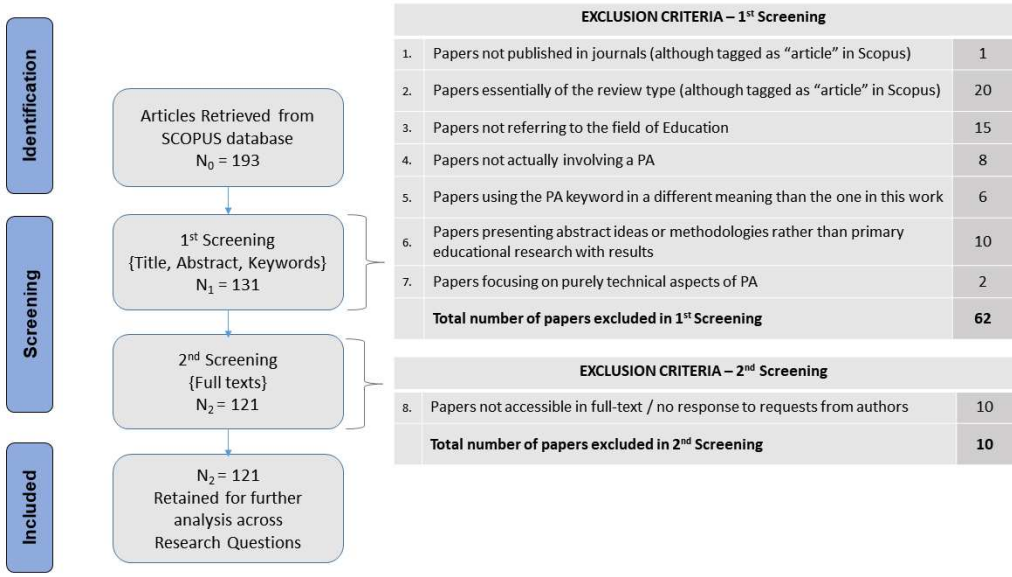
The initial query used as inclusion criteria was (a) the keyword "Pedagogical Agent," (b) the 2009 to 2022 period, (c) the "article" (not "review") type of publication, (d) the "journal" (not conference proceedings, books, or doctoral theses, etc.) source of publication, and (e) the English language. In response to the query "TITLE-ABS-KEY ("Pedagogical Agent") AND DOCTYPE (ar) AND PUBYEAR>2008 AND PUBYEAR<2023 AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j"))," a total of $N0 = 193$ articles are retrieved from Scopus.

The selection process proceeded in two successive screening phases. The first screening was performed on the basis of the {title, abstract, keywords} triplet only and used the following set of exclusion criteria to filter out publications deemed unsuitable for this review:

1. Papers not published in journals (although tagged as "article" in Scopus).
2. Papers essentially of the review type (although tagged as "article" in Scopus).
3. Papers not referring to the field of education.
4. Papers not actually involving a PA.
5. Papers using the PA keyword in a different meaning than the one in this work.
6. Papers presenting abstract ideas or methodologies rather than primary educational research with results.
7. Papers focusing on the purely technical aspects of PAs.

This first screening was performed independently by the first two authors, with an inter-rater reliability index of $k = 0.87$. Publications where author decisions disagreed were treated more carefully; the full text was retrieved and studied by all three authors, and the final inclusion/exclusion decision was taken unanimously after discussion. According to the exclusion criteria set, sixty-two papers were excluded, leaving a body of $N_0 - 62 = N_1 = 131$ papers for full-text retrieval and analysis (see Figure 1).

The second screening was performed on the basis of the full-text publications retrieved and studied jointly by the first two authors. Retrieval was performed by online search and, in certain cases, by e-mail requests to authors. The sole exclusion criterion in this second screening was the final inaccessibility of the full text of an article. Ten more articles were thus excluded, resulting in a body of $N_1 - 10 = N_2 = 121$ articles retained for further analysis across the RQs defined in the Introduction. These $N_2 = 121$ articles are separately listed in the Appendix, in alphabetic order.



EXCLUSION CRITERIA – 1st Screening		
1.	Papers not published in journals (although tagged as "article" in Scopus)	1
2.	Papers essentially of the review type (although tagged as "article" in Scopus)	20
3.	Papers not referring to the field of Education	15
4.	Papers not actually involving a PA	8
5.	Papers using the PA keyword in a different meaning than the one in this work	6
6.	Papers presenting abstract ideas or methodologies rather than primary educational research with results	10
7.	Papers focusing on purely technical aspects of PA	2
	Total number of papers excluded in 1st Screening	**62**

EXCLUSION CRITERIA – 2nd Screening		
8.	Papers not accessible in full-text / no response to requests from authors	10
	Total number of papers excluded in 2nd Screening	**10**

Figure 1: Complete Paper Retrieval and Selection Process

Analysis and Results

How Popular Is the Subject of PAs in Education within Recent Research?

Research results reported in publications serve as the basis on which the popularity of PA-related research is judged. Journal publication counts along publication year are given in Table 1 and shown in Figure 2 for the reviewed period (2009–2022). Both the count of originally retrieved publications and the count of publications eventually selected for analysis

are shown per year. Neither an increasing nor a decreasing trend can be claimed on the basis of Figure 2; rather, results indicate a sustained research interest in the field over time. It is worth reporting that a similar behavior was detected on two searches the authors performed (1) on review papers on PAs and (2) on conference papers on PAs, although out of the scope of the present work. Furthermore, the slight decrease detected during the last three years (2020–2022) may be attributed to the COVID-19 pandemic and the consequent shift of priorities in education to cover emergency needs.

A possible explanation of this "sustained interest" behavior stems from the very nature of the educational research on PAs, which poses serious practical issues: the researcher must have had access to an operational e-learning environment "equipped" with a PA under one or more forms and the authorization to plan and carry out educational interventions that involve the PA in interaction with human learners. Such demands clearly exceed those posed by a mere simulation study. Moreover, experimentation with the form, type, and modalities of the PA requires, in fact, a multi-disciplinary team with programming, design, and pedagogical skills. It is not surprising, therefore, that relevant research publications do not exhibit a pronounced (increasing) trend.

Table 1: Publications Count per Year (Retrieved and Selected)

Year	*Retrieved Publications Count (Absolute Number)*	*Selected Publications Count (Absolute Number)*	*Selected Publications Citations (Author(s) Year)*
2009	12	5	(Baylor and Kim 2009; Bodenheimer et al. 2009; Cheng et al. 2009; Kim et al. 2009; Veletsianos 2009)
2010	17	12	(Azevedo et al. 2010; Domagk 2010; Graesser and McNamara 2010; Hodhod, Kudenko, and Cairns 2010; McQuiggan, Robison, and Lester 2010; Moreno, Reislein, and Ozogul 2010; Morton and Jack 2010; Murray and Tenenbaum 2010; Rosenberg-Kima et al. 2010; Veletsianos 2010; Yan and Agada 2010; Yang and Zapata-Rivera 2010)
2011	7	3	(Kim and Wei 2011; Lee and Osman 2011; Theodoridou 2011)
2012	18	10	(Bowman 2012; Chen et al. 2012; Cheng and Chen 2012; D'Mello et al. 2012; Kuk et al. 2012; Lee and Osman 2012; Rodrigo et al. 2012; Subri, Abbas, and Shah 2012; Unal-Colak and Ozan 2012; Veletsianos 2012)
2013	16	9	(Arroyo et al. 2013; Johnson, Didonato, and Reisslein 2013; Johnson et al. 2013; Kim 2013; Liew, Tan, and Jayothisa 2013; Ozogul et al. 2013; Van Der Meij 2013a, 2013b; Veletsianos and Russell 2013)
2014	13	8	(Bernardini, Porayska-Pomsta, and Smith 2014; Hong, Chen, and Lan 2014; Noh et al. 2014; Osman and Lee 2014; Poitras and Lajoie 2014; Romero-Hall, Watson, and Papelis 2014; Taub et al. 2014; Trevors, Duffy, and Azevedo 2014)

Year	*Retrieved Publications Count (Absolute Number)*	*Selected Publications Count (Absolute Number)*	*Selected Publications Citations (Author(s) Year)*
2015	16	13	(Chen and Chou 2015; Craig et al. 2015; Duffy and Azevedo 2015; Goldberg and Cannon-Bowers 2015; Ivanovic et al. 2015; Johnson, Ozogul, and Reisslein 2015; Lee, Kanakogi, and Hiraki 2015; Park 2015; Schroeder and Adesope 2015; Shiban et al. 2015; Tegos, Demetriadis, and Karakostas 2015; Van der Meij, Van der Meij, and Harmsen 2015; Yung and Paas 2015)
2016	19	15	(Bernstein et al. 2016; Carlotto and Jaques 2016; Chatzara, Karagiannidis, and Stamatis 2016; Chin et al. 2016; Harley et al. 2016; Hassani, Nahvi, and Ahmadi 2016; Hayashi 2016; Hernández et al. 2016; Huang and Mayer 2016; Kim 2016; Krämer et al. 2016; Li et al. 2016; Liew et al. 2016; Martins et al. 2016; Terzidou et al. 2016)
2017	15	11	(Ahmadi, Sahragard, and Babaie Shalmani 2017; Beege et al. 2017; Cook et al. 2017; Craig and Schroeder 2017; Dinçer and Doğanay 2017; Graesser, Forsyth, and Lehman 2017; Kim, Thayne, and Wei 2017; Liew, Mat Zin, and Sahari 2017; Schroeder 2017; Schroeder and Craig 2017; Schroeder and Traxler 2017)
2018	15	11	(Bringula et al. 2018; Harley et al. 2018; Karaoğlan Yılmaz, Olpak, and Yılmaz 2018; Le and Wartschinski 2018; Mohammadhasani et al. 2018; Munawar et al. 2018; Nielen et al. 2018; Saadatzi et al. 2018; Schroeder et al. 2018; Sullins et al. 2018; Terzidou, Tsiatsos, and Apostolidis 2018)
2019	15	9	(Davis, Vincent, and Park 2019a, 2019b; Fountoukidou et al. 2019; Kappagantula et al. 2019; Kautzmann and Jaques 2019; Makransky, Wismer, and Mayer 2019; Scholten, Kelders, and Van Gemert-Pijnen 2019; Schroeder, Chin, and Craig 2019; Tärning and Silvervarg 2019)
2020	12	6	(Beege et al. 2020; Buttussi and Chittaro 2020; Chiou, Schroeder, and Craig 2020; Lin et al. 2020; Rosenthal-von der Pütten and Bergmann 2020; Yilmaz and Karaoğlan Yilmaz 2020)
2021	7	4	(Ferro et al. 2021; Horovitz and Mayer 2021; O'Connor et al. 2021; Schroeder, Chiou, and Craig 2021)
2022	11	5	(Bian 2022; Darejeh, Marcus, and Sweller 2022; Dell'Aquila et al. 2022; Lawson and Mayer 2022; Li et al. 2022)
Total	193	121	

Note: All corresponding references for these selected citations can be found in the Appendix.

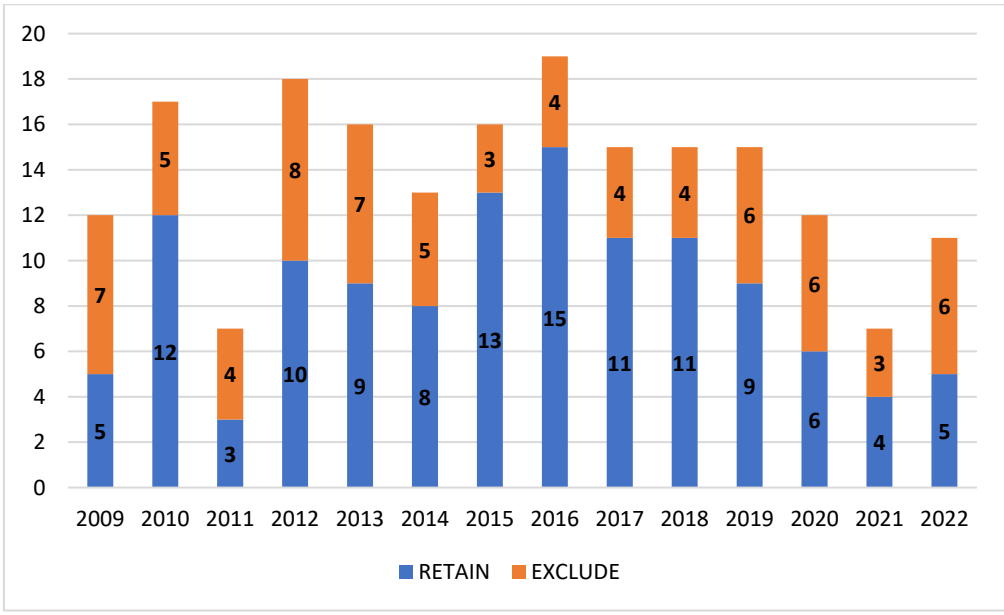


Figure 2: Publications Count per Year along the Review Year Span (2009–2022)
Note: Papers Retrieved (Total), Papers Excluded (Red), Papers Retained (Blue)

In What Education Grades Does Relevant Research Take Place?

The grade of education where relevant research takes place is tabulated in Table 2 and visualized in Figure 3. The results reveal that 44 of the 121 studies (36%) take place at the university (undergraduate) level, while 30 out of the 121 studies (25%) take place at the high-school/secondary education level. Primary school, professional, college, and university-graduate education follow, with decreasing frequencies; no study refers to preschool education or kindergarten—a plausible result given the needs and sensitivities of early childhood education.

Table 2: Education Grades Where PA-Related Research Takes Place (Absolute Numbers and Percentages)

Education Grade	*Publications Count (Absolute Number)*	*Publications Count (Percentage)*
Preschool/Kindergarten	0	0
Primary School (Grades 1–6)	12	10
High School/Secondary (Grades 7–12)	30	25
College	12	10
University-Undergraduate	44	36
University-Graduate/Postgraduate	7	6
Professional/Vocational	14	11
Informal Learning	2	2
Total	121	100

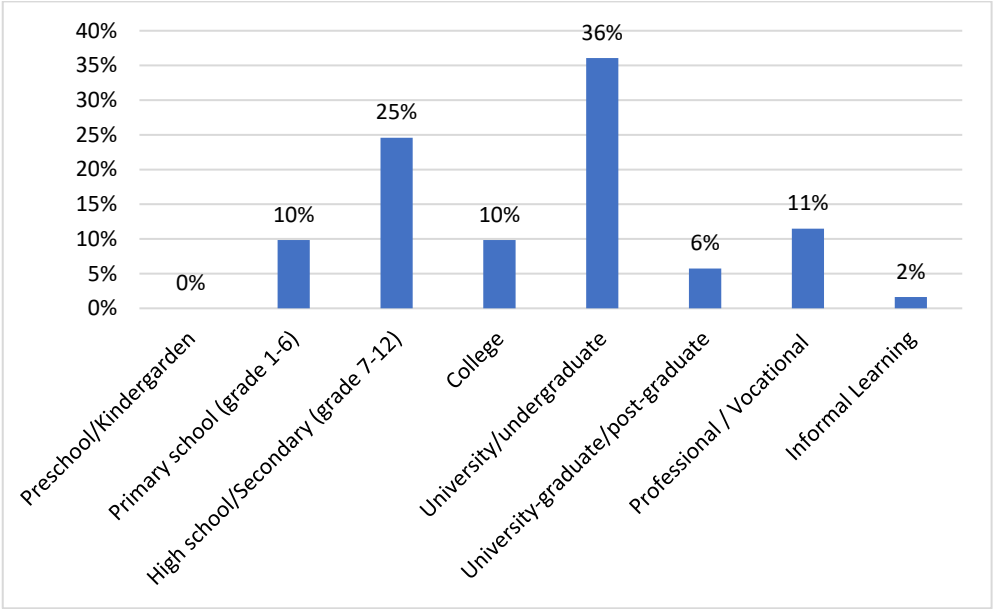


Figure 3: Education Grades Where PA-Related Research Takes Place (Percentages across Education Grades)

In the Context of Which Taught/Studied Subjects Are PAs Introduced?

PA-related research is conducted in classes teaching a wide spectrum of different subjects. For the purposes of this review, subjects are grouped into greater families of disciplines. Results are given in Table 3 and Figure 4. For analysis purposes, Computer Science (twenty four studies or 20%) and Mathematics (fifteen studies or 12%) are shown as separate subjects, while all other sciences are shown as another aggregate subject (twenty six studies or 21%). Results reveal that Sciences collectively account for half the research activity reviewed. Indeed, they head the list with 26 (Other Sciences) + 24 (Computer Science) + 15 (Mathematics) = 65 studies or 53 percent. Languages, Health and Medical subjects, Engineering, Psychology as a separate subject, Other Social Sciences collectively, Humanities in general, Special Education, Sports and Physical Education, Business and Finance, and Other subjects (miscellaneous subjects not classified elsewhere in this taxonomy) follow, with decreasing frequencies. The leading place of Sciences, especially Computer Science in the list of subjects does not come as a surprise, since PAs are essentially software engineering constructs. It is reasonable that researchers who design and develop PAs tend to test and assess them primarily in their own field of study. The high frequency of appearance of Mathematics as a test-bed for PAs, on the other hand, does beg for an explanation other than the notoriety of the subject with certain categories of students.

Table 3: Study Subjects Where PAs Are Employed (Absolute Numbers and Percentages)

Study Subjects	*Publications Count (Absolute Number)*	*Publications Count (Percentage)*
Business and Finance	1	1
Other	1	1
Sports and Physical Activity	2	2
Special Education	3	2
Humanities	6	5
Psychology	7	6
Social Sciences	7	6
Engineering	8	7
Health and Medical Sciences	9	7
Languages	12	10
Mathematics	15	12
Computer Science	24	20
Sciences	26	21
Total	121	100

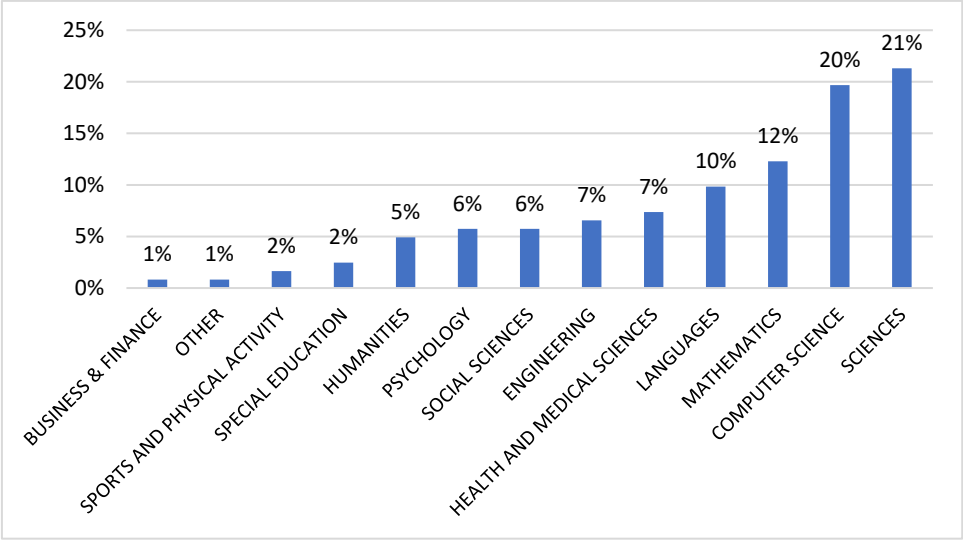


Figure 4: Study Subjects Where PAs Are Employed, in Ascending Order

What Are the Most Popular Forms/Types/Communication Modalities of PAs?

Six classes are defined for the classification of the 121 reviewed studies as to the type and form of the PA and the employed communication means, namely, {text-only, voice-only, text-plus-voice-or-audio, image-only, image-plus-voice-or-audio, animated figure}. For a more detailed analysis, within the last three classes that employ images, either still or moving, three subclasses are adopted: {male, female, nonhuman-like}. It is clear that a single research may (and typically will) involve more than one of these classes and/or subclasses. Results are given in Tables 4 and 5 and shown in Figure 5.

Table 4: PA Forms, Types, and Communication Modalities (Absolute Numbers and Percentages): Major Classes

PA Forms, Types, and Communication Modalities: Major Classes	*Publications Count (Absolute Number)*	*Publications Count (Percentage)*
Text-Only	12	10
Voice-Only	7	6
Text-Plus-Voice-or-Audio	3	2
Image-Only	23	19
Image-Plus-Voice-or-Audio	27	22
Animated Figure	64	52

Table 5: Forms, Types, and Communication Modalities (Absolute Numbers and Percentages): Subclasses

PA Forms, Types, and Communication Modalities: Subclasses	*Publications Count (Absolute Number)*	*Publications Count (Percentage)*
Image-only: male	10	8.2
Image-only: female	6	4.9
Image-only: nonhuman-like	7	5.7
Image-plus-voice or audio: male	10	8.2
Image-plus-voice or audio: female	18	14.8
Image-plus-voice or audio: nonhuman-like	1	0.8
Animated figure: male	28	23.0
Animated figure: female	38	31.1
Animated figure: nonhuman-like	10	8.2

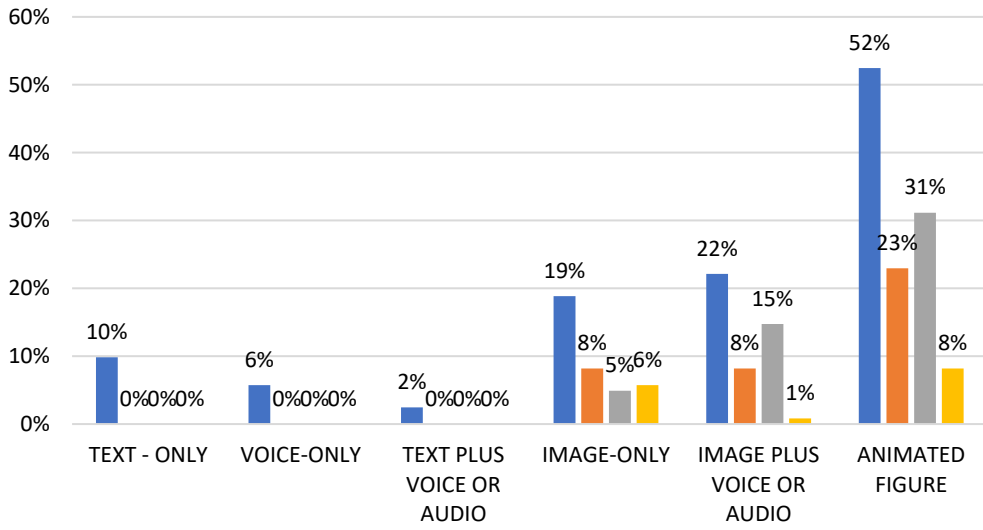


Figure 5: PA Forms, Types, and Communication Modalities across the Six Major Classes Adopted Here
Note: In classes "Image-Only," "Image-Plus-Voice or Audio," and "Animated Figure," three subclasses are shown: Red: Male PA; Grey: Female PA; Yellow: Nonhuman-Like PA

As can be easily detected in Figure 5, the three last classes that involve images account for the vast majority of cases. Indeed, 113 of 121 cases or 93.4 percent employ PAs that appear as figures, either moving/speaking or not, while only 21 out of 121 cases or 17.4 percent employ PAs that are disembodied voices ("Voice-only"), text messages ("Text-only"), or a combination of the two ("Text-plus-voice or audio"). Within the last three classes ("Image-only," "Image-plus-voice or audio," "Animated figure"), more than half the studies (63 of the 113 cases or 55.7%) resort to animation ("Animated figure"). The strength of the image, especially of the animated image, has repeatedly been verified across existing research (e.g., the persona effect).

As to the form of the image employed, human-like figures are preferred to non-human-like figures uniformly across classes "Image-only," "Image-plus-voice or audio," and "Animated figure," while female PAs are preferred over male PAs in classes "Image-plus-voice or audio" and "Animated figure." Female PAs are the dominant choice when all modalities are grouped together. Such results agree with existing research on PA sex and its impact (Griffin 1997).

What Is the Learning Theory Underlying Educational Interventions with PAs?

In principle, the design and implementation of any educational intervention should be based on one or more theories of learning and consequently adopt suitable educational methods and implementation scenarios that put to practice the essential ideas of the relevant theory/-ies. In order to investigate this aspect of PA-related educational research, the present review has adopted a spectrum of theories of learning, namely, behaviorism, constructivism/inquiry-based learning/problem solving/learning by doing, collaborative learning/game-based learning, and observational learning. The analysis of the 122 papers across these categories has given the results shown in Table 6 and Figure 6. As it can be seen in these results, behaviorism is the most common theory of learning adopted in PA-related research, accounting for 2 out of every 3 research studies (80 out of 121 cases or 66%). Constructivism follows with 28 out of 121 cases or 23 percent. Collaborative learning is employed in 10 out of 121 cases or 8 percent while closely related game-based learning is employed in 12 out of 121 cases or 10 percent. Learning by doing is adopted in 8 out of 121 cases or 7 percent; problem solving is adopted in 7 out of 121 cases or 6 percent; and inquiry-based learning is adopted in 3 out of 121 cases or 2 percent. Observational learning accounts for 2 out of 121 cases or 2 percent, while a single study (1%) cannot be assigned to any of these theories.

It is important to note that most of these results do not come from a clear relevant statement of the publication authors; rather, they are concluded by the authors of the present review, after analysis of each education intervention reported in the 121 cases. In fact, hardly any of the 121 publications refer explicitly to any overarching theory of learning—an alarming result given the high cost of PA-related research in terms of resources. Furthermore, certain of the 121 research studies are assigned to more than one learning theory, especially those that perform comparative evaluations of various PA aspects or functionalities.

The dominant role of behaviorism, as apparent in the results, is another alarming result. Specifically, the majority of the reviewed educational interventions employ a video that includes the PA, and participants (learners) are typically asked to watch the video(s) and answer questionnaires, quizzes, or interviews afterwards. A possible explanation for the popularity of this strongly behavioristic scenario is the simplicity of its design and implementation. Certainly, the development of a PA-supported educational scenario that implements constructivistic or collaborative theories of learning is far more demanding than the production of a video that includes a PA. On the other hand, behaviorism has long received severe criticism as a pedagogical method that ignores/does not promote student initiative, motivation, cognition, or thought. Constructivistic and collaborative theories of learning have been progressively adopted in the previous century; behavioristic approaches are today considered outdated and are limited to specific settings and audiences. In that sense, the reviewed field constitutes an unusual combination of state-of-the-art technology with obsolete pedagogical approaches.

Table 6: Learning Theories Adopted in PA-Related Research (Absolute Numbers and Percentages)

Learning Theory	*Publications Count (Absolute Number)*	*Publications Count (Percentage)*
Behaviorism	80	66
Constructivism	28	23
Game-Based Learning	12	10
Collaborative Learning	10	8
Learning by Doing	8	7
Problem Solving	7	6
Inquiry-Based Learning	3	2
Observational Learning	2	2
N/A	1	1

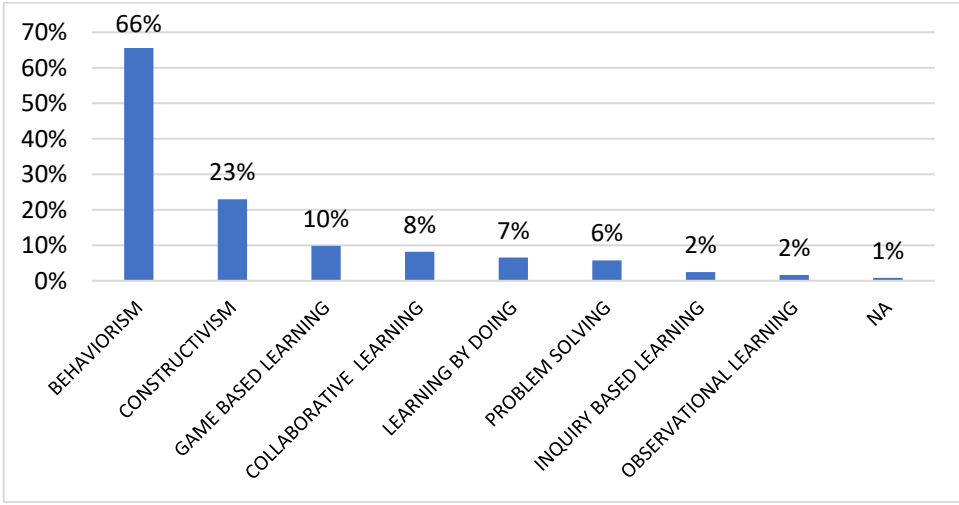


Figure 6: Learning Theories Adopted in PA-Related Research (Percentages), in Descending Order

At What Time Points/Periods Are Measurements Taken for Evaluation?

The evaluation method employed to measure the learners' performance is an important factor across all educational interventions. Evaluation is expected to accurately measure the "added value" of the specific intervention to the learners' knowledge, skills, and competences along the various axes of interest for the specific research, e.g., learning outcomes, social skills (communication, collaboration), metacognitive skills (motivation, self-efficacy, affective state, emotion manipulation/control, etc.).

Indeed, throughout the 121 reviewed publications, students/learners are assessed along the axis(es) of interest in the learning process, per case. It is also interesting that only one (1) out of the 121 cases (1%) does not include an assessment method at all, or the assessment method is not mentioned or specified.

The impact of the intervention on the target group along each of these axes is measured using two major approaches:

1. The first approach uses two measurement time points, one before the intervention (pretest) and one closely after it (posttest). Although this is considered the conventional approach, it is a mature and well-studied process, and many evaluation tools are available for the construction and delivery of case-pertinent tests. Before the intervention, a pretest is delivered to identify the weak points or gaps in student knowledge within the specific taught subject. The posttest is matched to the pretest in order to facilitate the comparison and estimation of the student's progress.
2. The second approach monitors the learners' behavior and interaction during the whole intervention, or at frequent time points throughout it. This is considered a pedagogically more appropriate process, as it is expected to yield more accurate and detailed results that will closely reflect the measured quantities. It is a far more demanding procedure, however, in terms of the resources needed, preparation, and organization.

Pre- and posttesting is a commonly used instrument in most of the reviewed works to evaluate the students' knowledge after the intervention in comparison to that before the intervention. The results given in Table 7 and shown in Figure 7 verify that this method is employed by 75 percent of the reviewed works (91 out of 121 papers) because it is relatively simple to implement and it provides clear evidence of the effectiveness of the used teaching methodologies. It is worth mentioning that 21 percent of the studies (26 out of 121 papers) use posttesting only. In these cases, it is difficult to determine the step of the measured outcomes, whether knowledge increased or not, as well as whether the outcomes are due to the used method/PA or not.

Continuous monitoring, denoted as "During" in Figure 7, is employed in 22 percent of the cases (27 out of 121 papers). This mediocre result reveals that the efficacy of the learning method and the instructional intervention before, during, and after the learning process at multiple points of each program is feasible yet not so popular, probably because of the time and effort required.

Despite the fact that continuous monitoring is time- and effort-consuming to implement, it offers a more objective and accurate evaluation of student progress along the social skills and the metacognitive skills axes, besides the cognitive axis—which is not possible through pre- and/or posttesting alone.

Table 7: Time Points/Periods Where Measurement Data Is Collected for Evaluation Purposes (Absolute Numbers and Percentages)

Time Points/Periods Where Measurement Data Is Collected for Evaluation Purposes	*Publications Count (Absolute Number)*	*Publications Count (Percentage)*
Pretest Only	0	0
Pretest and Posttest	91	75
Posttest Only	26	21
During the Intervention	27	22
N/A	1	1

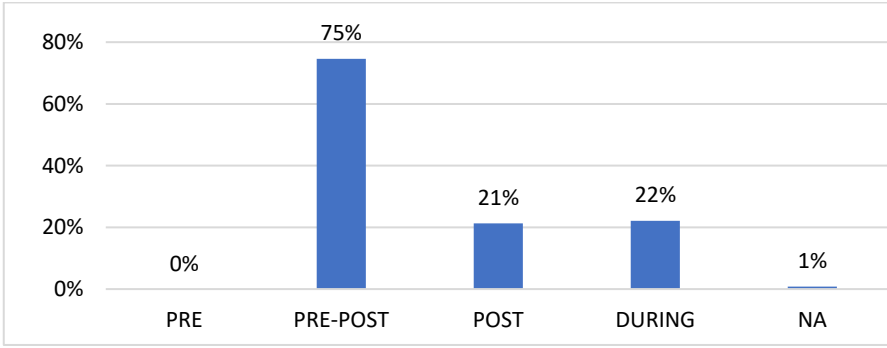


Figure 7: Time Points Where Measurement Data Are Collected for Evaluation Purposes (Absolute Numbers and Percentages)

What Are the Research Results on Learning Outcomes Achieved with PAs?

Assessment of the learning outcomes obtained with the aid of PAs is the prime and most essential means to judge the agent's efficiency in the educational—and not the purely technical—aspect. An intensely researched, mature, and highly diversified domain in its own right, the assessment of learning outcomes is carried out across the 121 reviewed studies through a variety of methods, including tests, questionnaires, interviews, and skill certification exams. In the present analysis, a six-level classification scheme is adopted for the learning outcomes achieved and reported in each study, namely {positive, positive-neutral, neutral, negative-neutral, negative, mixed (positive and negative)} along with a seventh class for studies that do not assess learning outcomes at all.

Results in Table 8 and Figure 8 reveal a strong majority of studies reporting a positive impact of the PA on the learning outcomes achieved, meaning that the students' knowledge and skills on the subject taught or studied have been measured before and after the intervention with the PA and found to be increased. This is the case reported in the vast

majority of the reviewed studies (78 + 6 = 84 out of the 121 or 69%). Ten studies or 8 percent report neutral results (no impact of the agent on the learning outcomes), while few studies (2 + 2 = 4 or 4%) report negative results (students interacting with the PA perform lower than a control group without PA). Mixed results (positive for a certain condition and negative for another condition) are reported in nine studies or 7 percent while fourteen studies or 11 percent do not include assessments of learning outcomes at all.

Table 8: Results Reported in the Reviewed Publications on the Learning Outcomes Achieved with the Aid of PAs

Results Reported on the Learning Outcomes Achieved (Cognitive Domain)	*Publications Count (Absolute Number)*	*Publications Count (Percentage)*
Positive	78	64
Positive-Neutral	6	5
Neutral	10	8
Negative-Neutral	2	2
Negative	2	2
Mixed	9	7
N/A	14	11
Total	121	100

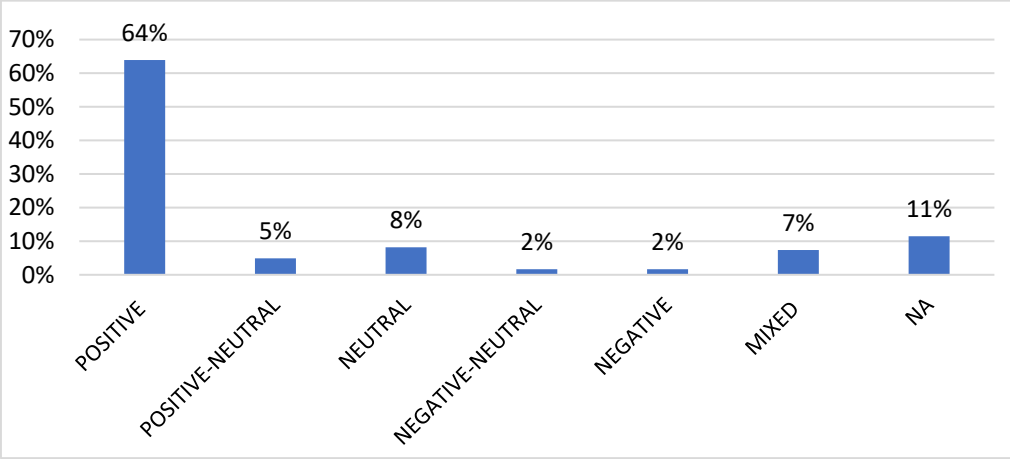


Figure 8: Results Reported in the Reviewed Publications on the Learning Outcomes Achieved with the Aid of PAs

The potential of the PAs as efficient "educators" is established through these results. A different reading of the same table, however, would point out that 15 percent of the studies report essentially neutral or close to neutral results (6 + 10 + 2 = 18 out of the 121 or 15%), meaning that the impact of the PA on the progress/gains of students in the cognitive domain is negligible, despite the fact that the development of a learning environment with an operational PA in it costs dearly in terms of resources. If almost neutral cases are taken jointly with the negative and mixed cases, it seems that in 6 + 10 + 2 + 2 + 9 = 29 out of 121 cases or 24 percent the decision to develop

and use a PA is not safely justified by the gains in learning outcomes. With this percentage certainly not negligible, it becomes clear that gains in other domains should come into play to support the use of PAs. These might be the learners' social/collaborative skills, their self-efficacy (Bandura 1997; Zimmerman 2000a), their self-esteem and confidence, their motivation (Pintrich and Zusho 2002), self-regulated learning skills (Zimmerman 2000b), and metacognitive skills (Pintrich, Wolters, and Baxter 2000; Hartman 2002). A final comment refers to the nonnegligible number of studies (14/121 or 11%) that do not aim at increasing or do not measure and evaluate learning outcomes in the cognitive domain.

What Are the Research Results on the Development of Social Skills with PAs?

The development of social skills constitutes a major aim of education, be it face-to-face instruction or distance/e-learning. Social skills allow students to better communicate their ideas, explain their views and opinions, give and receive feedback, and be more open to explicit as well as implicit ways of social learning (Assareh and Bidokht 2011). Indeed, communication and collaboration hold top positions in the list of "21st century" or "soft" skills, along with creative thinking and critical thinking (Mazeh 2020). The interaction of the learner with the PA(s) and possibly other classmates or virtual characters in a virtual learning environment, realized through various media and modalities, may provide a basis for the development of social skills.

Despite their importance in any educational context, however, social skills are an under-researched domain, as can be seen in the results in Table 9 and the corresponding Figure 9. Practically 3 out of every 4 studies (89 out of 121 studies or 73%) do not include any social skills in their education objectives. Those 28 out of the total of 121 studies or 27 percent that do refer to social skills report mostly positive outcomes (23%). Only two studies report mixed results, while two more studies report negative results. These results show that the learners gain a clear benefit from their interaction with the PA(s) and possibly with other classmates or virtual characters. A possible reason for this limited research interest in social skills development through the PAs is the inherent difficulty in their measurement and assessment. In contrast to learning outcomes in the cognitive domain that are readily measured by pre- and posttests, measurement of social skills development would require more cumbersome and time-consuming tools such as monitoring of the student behavior throughout the learning session(s) and interviews or focus groups following the learning session(s). A general lack of commitment of study programs to social skills development is another possible tacit cause. The dominance of behaviorism in PA-related interventions, as documented in an earlier paragraph herein, is yet another cause: social skills development constitutes a side effect rather than a declared target of behavioristic approaches.

Table 9: Results Reported in the Reviewed Publications on the Social Skills Developed with the Aid of PAs

Results Reported on the Social Skills Developed with the Aid of PAs	*Publications Count (Absolute Number)*	*Publications Count (Percentage)*
Positive	28	23
Neutral	0	0
Negative	2	2
Mixed	2	2
N/A	89	73
Total	121	100

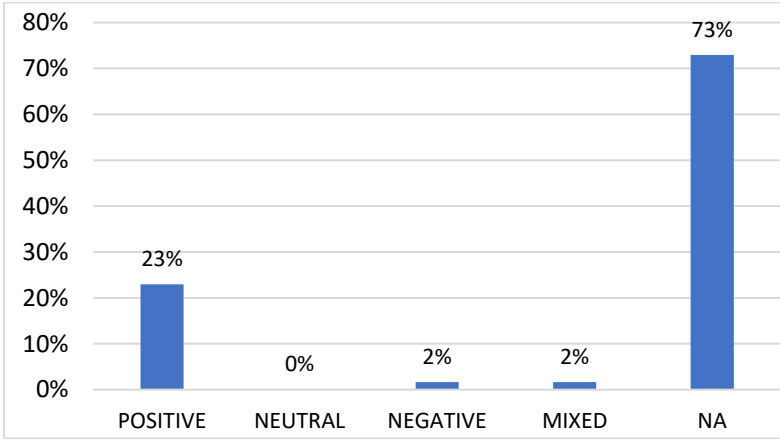


Figure 9: Results Reported in the Reviewed Publications on the Social Skills Developed with the Aid of PAs

What Are the Research Results on the Development of Affective Skills with PAs?

The affective or emotional state of the learner has long been recognized as critical to the success of the learning process. In contrast to older theories that considered knowledge and emotions as incompatible, modern learning theories have established that the correct affect greatly influences the quality of learning. Positive emotions facilitate and enhance learning, while negative emotions inhibit it (Mayer 2020). Apart from the immediate benefit, a positive learning experience is expected to bring about positive attitudes toward learning in general and to thus act as a booster of the learner's motivation for future and possibly life-long learning, i.e., help the learner develop metacognitive skills (Huang and Chang 2013).

As it can be seen in Table 10 and Figure 10, affective skills are targeted by approximately half the reviewed studies, while 67 out of 121 or 55 percent leave affective skills out of their focus. Among those studies that investigate affective skills, the vast majority (36 out of 54 or 66%) report positive results (increased affective skills), while eleven studies report neutral results, two studies report negative results, and five studies report mixed results.

A closer look into those publications that investigate affective skills reveals that the majority aims to answer questions such as whether students liked the PA or not, whether they

achieved a social rapport with the PA or not, whether they developed a trusting relationship with the PA or not, whether they had an overall pleasant or joyful experience, etc. The answers to such questions have an evident usefulness for PA designers and developers as feedback for improvements. They do not establish that the positive affective states of the learners will survive the duration of the interaction, however. Longitudinal studies would be needed to establish more permanent outcomes in the affective domain.

Table 10: Results Reported in the Reviewed Publications on the Affective Skills Developed with the Aid of PAs

Results Reported on the Affective Skills Developed with the Aid of PAs	*Publications Count (Absolute Number)*	*Publications Count (Percentage)*
Positive	36	30
Neutral	11	9
Negative	2	2
Mixed	5	4
N/A	67	55
Total	121	100

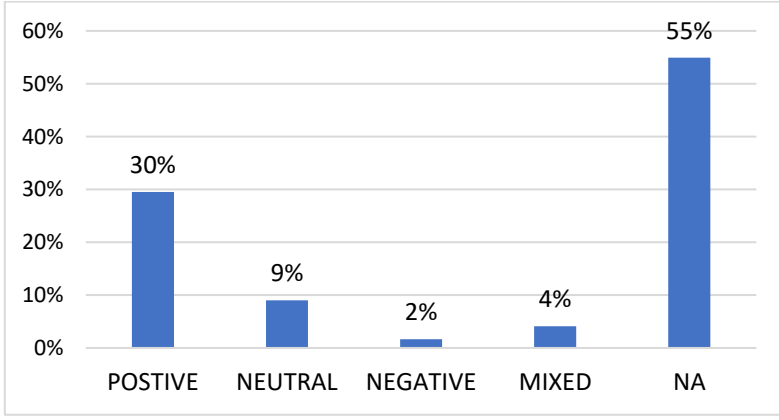


Figure 10: Results Reported in the Reviewed Publications on the Affective Skills Developed with the Aid of PAs

What Are the Research Results on the Development of Metacognitive Skills with PAs?

A wealth of desirable skills and attitudes come under the umbrella of the "metacognitive skills" collective term. Initiative, task relevance, self-esteem, self-efficacy, and self-regulated learning are the most popular entries in this set. Metacognition is highly desirable, yet it is hard to attain as a learning outcome—primarily because it requires an internal process of personality development and maturity in the individual. It is even more tough to measure and assess, although certain task-specific questionnaires are available.

As it can be seen in Table 11 and the corresponding Figure 11, metacognitive skills are out of the focus of 103 out of 121 studies (85%). Of the eighteen studies that do investigate metacognitive skills, fifteen report positive results, two report negative results, and one

reports mixed results. This limited research interest in the metacognitive domain is in contrast to the high potential of the PAs to develop the specific types of skills in the learners. Indeed, PAs are meant to support and scaffold learners so that they gain self-confidence in the specific tasks and, therefore, obtain self-esteem, progressively self-efficacy, and eventually self-regulation in their learning. PA technology offers possible window of opportunity for further research and development along the metacognitive axis.

Table 11: Results Reported in the Reviewed Publications on the Metacognitive Skills Developed with the Aid of PAs

Results Reported on the Metacognitive Skills Developed with the Aid of PAs	*Publications Count (Absolute Number)*	*Publications Count (Percentage)*
Positive	15	12
Neutral	0	0
Negative	2	2
Mixed	1	1
N/A	103	85
Total	121	100

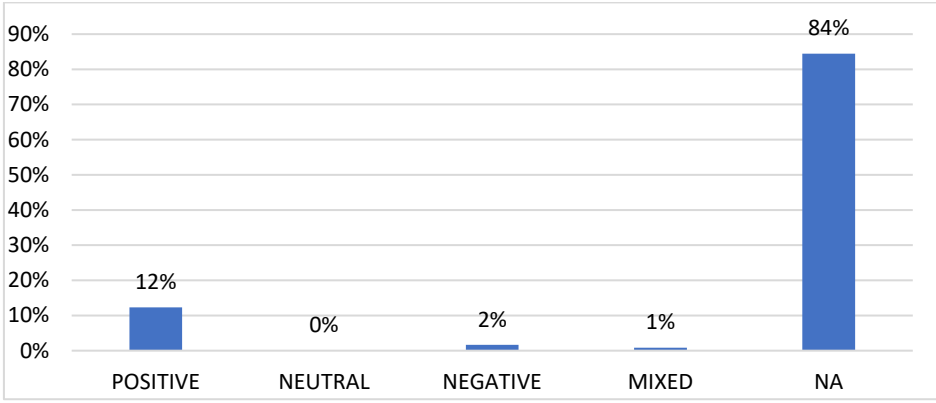


Figure 11: Results Reported in the Reviewed Publications on the Metacognitive Skills Developed with the Aid of PAs

What Are the Research Results on Motivation of Students by PAs?

A major aim that PAs are expected to attain is to engage and motivate learners. The importance of motivation for learning cannot be understated: it facilitates learning by creating the necessary attitude of the learners toward both the learning process and the subject studied (Yahiaoui et al. 2022). Eventually, motivated learners become more autonomous, self-confident, engaged, interested, and efficient in their studies. While extrinsic motivation in the form of rewards, benefits, or other gains is often used, it is intrinsic motivation stemming from an internal source within the individual that proves stronger, long-lasting, and more effective (Csikszentmihalyi 2014; Fishbach and Woolley 2022). Motivation may be roughly described as a two-stage process that initially emerges as a

temporary attraction of the interest ("situational interest") and later on, under conditions, develops into a long-lasting interest (long-term motivation) that may accompany the individual for life (Hartnett 2016; Fryer and Bovee 2016).

As it can be seen in Table 12 and the corresponding Figure 12, the motivation of the learners by the PA was not researched in 42 percent of the studies. Among the 58 percent of the studies that do research on the development of situational interest in the learners thanks to the PA, the vast majority (57%) report positive results (the PA does achieve increased interest of the learner in the short term), while a single study (1%) reports neutral results.

Table 12: Results Reported in the Reviewed Publications on the Motivation (Situational Interest) Developed with the Aid of PAs

Results Reported on the Motivation (Situational Interest) Developed with the Aid of PAs	*Publications Count (Absolute Number)*	*Publications Count (Percentage)*
Positive	69	57
Neutral	1	1
Negative	0	0
Mixed	0	0
N/A	51	42
Total	121	100

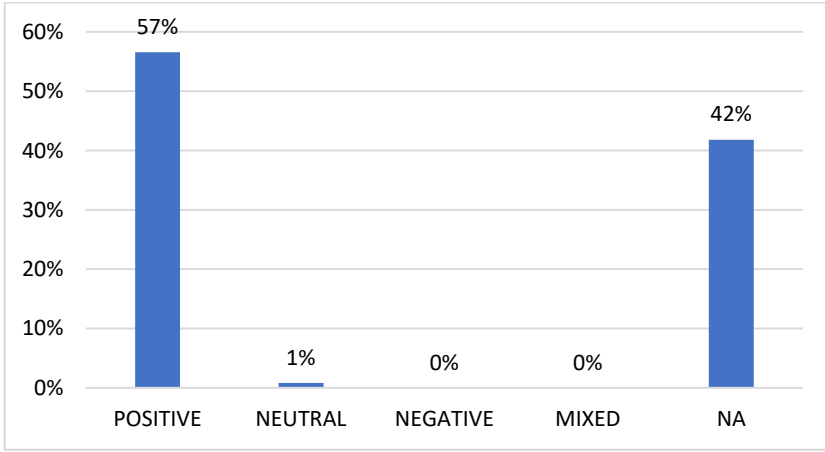


Figure 12: Results Reported in the Reviewed Publications on the Motivation (Situational Interest) Developed with the Aid of PAs

The general picture regarding the long-term motivation developed thanks to the PA is similar to that regarding situational interest, yet at a somehow lower level. As it can be seen in Table 13 and the corresponding Figure 13, the motivation of the learners by the PA was not researched in half of the reviewed studies (51%). Among the 49 percent of the studies that do research on the development of long-term motivation in the learners thanks to the PA, the vast majority (37%) report positive results (the PA does increase the interest of the learner

in the short term), ten studies (8%) report neutral results, a single study (1%) reports negative results, and three studies (2%) report mixed results, case-dependent.

Table 13: Results Reported in the Reviewed Publications on the Motivation (Long-Term Interest) Developed with the Aid of PAs

Results Reported on the Motivation (Long-Term Interest) Developed with the Aid of PAs	*Publications Count (Absolute Number)*	*Publications Count (Percentage)*
Positive	45	37
Neutral	10	8
Negative	1	1
Mixed	3	2
N/A	62	51
Total	121	100

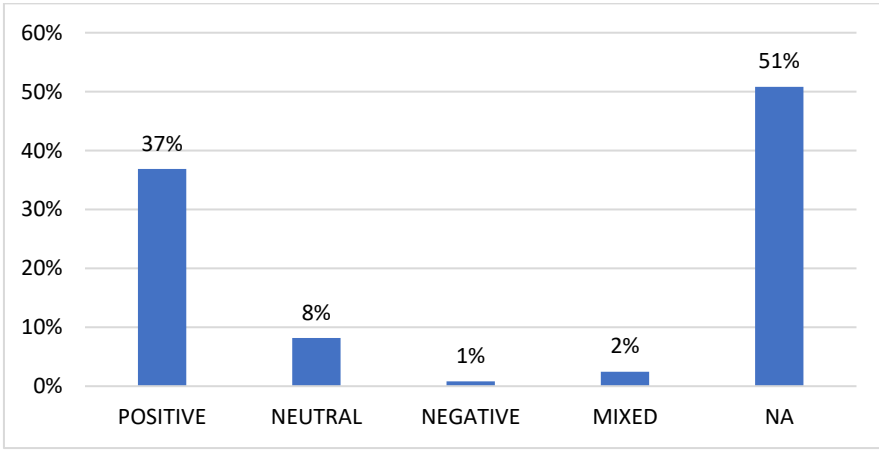


Figure 13: Results Reported in the Reviewed Publications on the Motivation (Long-Term Interest) Developed with the Aid of PAs

An observation from the comparison of Tables 12 and 13 is that short-term interest is easier to get and more frequent to research than long-term motivation. This is not a surprising result; in fact, all modern technologies involved in education and learning share that feature with PA technology (Papoutsi and Rangoussi 2020; Lane and Schroeder 2022; Sikström et al. 2022). The modern, high-tech look and feel of these technologies attract the interest of the learners, ignite a spark in them, and help establish a positive affect and attitude toward learning. In order for this initial spark to evolve into a long-term motivation, however, much more is needed: an educational method and a scenario of high educational and pedagogical quality, the establishment of correspondence between what is taught in class and the specific needs of the learner as well as the expectations of the job market from him/her, the societal value assigned to the subject, etc. Furthermore, external factors such as personal or family physical/mental health problems may distract the learners and inhibit the development of long-term

motivation. From another perspective, the role of the learning theory adopted and of the instruction method consequently implemented, behaviorism in the majority of the studies as revealed in RQ5, is another critical factor: it seems that watching videos and answering questionnaires does not facilitate the development of long-term motivation. Constructivistic and/or collaborative approaches might possibly prove more beneficial in that aspect.

Discussion

The first outcome of this analysis is that PAs constitute a domain of sustained rather than increasing or decreasing research interest. The "typical" research study opts for an anthropomorphic, animated, female PA; nonanthropomorphic as well as text-only or text and voice-audio solutions are also investigated. The vast majority of the reviewed studies focus on the learning outcomes achieved with the aid of the PA in the cognitive domain. Computer science courses at the undergraduate academic level constitute the basis for the majority of PA-aided interventions. The studies measure knowledge gains by pre- and posttests, with mostly positive results (increased knowledge in the taught subject). Monitoring user behavior and quality of interaction with the e-learning platform and the PA throughout the intervention would certainly be far more revealing as to the inner mechanisms of this type of learning. Few studies adopt such tools, however—an understandable choice, given that monitoring is more time- and resource-consuming.

Beyond learning outcomes, however, the aims of the reviewed studies are limited: aspects such as social skills (communication and collaboration), triggering of student interest (short- or long-term motivation), metacognitive skills (self-regulated learning), or affective skills (regulation of emotions) are overlooked by the (vast) majority of the studies. Those studies that do investigate such aspects report positive results—an interesting outcome that indicates the potential of PAs to develop relevant skills in learners. A major result that may prove to hold a cause-and-effect relationship with the above findings is that the majority of interventions (66%) adopt and apply behaviorism as the learning theory of choice, against a much lower 23 percent that uses constructivism and an 18 percent that uses collaborative/game-based learning. Along with the dominance of the pretest and posttest student evaluation methods, these findings describe an alarming picture of PA-aided learning as a high-technology but low-pedagogy field in education.

The implications of these findings should be examined along two paths: (1) the ways of embedding and using PAs in educational practice, and (2) the aims of research on the results of their use.

Regarding the first path, it should be noted that a consensus is reached today on the superiority of education scenarios based on constructivism, social constructivism, and socio-cultural learning theories over scenarios based on earlier theories such as behaviorism. In consequence, PA-aided education is expected to become more beneficial for the learners if it

is re-oriented to align with modern theories of learning and adopts less behavioristic and more constructivistic/collaborative methods.

Regarding the second path, an implication of the current analysis is the need to extend the scope of PA research to look into outcomes achieved in the social domain, the affective/emotional domain, the metacognitive domain, the experience, and the satisfaction of the learner. These under-researched sides of PA-aided learning may offer valuable insight as to the potential of PAs to improve learning in the respective domains. Given the research effort already invested in the examination of the technical soundness of PA constructs and applications, the field seems ready to shift focus to the evaluation of the learning outcomes achieved across multiple domains.

The evaluation methodology and tools used are critical points in this discussion. Indeed, they should also be aligned with the overarching learning theories and the specific research aims. While pretests and posttests may suffice for the measurement of new knowledge, student monitoring during interaction with the PA as well as interviews, focus groups, and discussions after it are more suitable to evaluate skills developed in the social, emotional/affective and metacognitive domains. Student monitoring may rely either on technical aids such as videos, face recognition, computer interaction measurements, etc., or on manual notes by human observers, or both. In either case, meticulous analysis is necessary in order to extract meaningful results.

The above directions may be of interest both for those parties who plan, fund, and design future research in the field of PAs in education and for those parties who develop, implement, and test new intelligent educational environments that include PAs. What emerges eloquently from the results of the current survey is that the community of all involved stakeholders should shift focus from the (already mature enough) technical aspects to the educational and pedagogical aims to be fulfilled. To this end, a more active role should be assigned to experts in education and pedagogy.

Conclusions–Further Research

The systematic literature review of recent (2009–2022) research studies on the uses of PAs in education has produced interesting results on the aims, objectives, methods, and outcomes of relevant research, as these are manifested through the 121 journal publications selected and analyzed in this work.

Two are the major novelties of the approach adopted: (1) Only those primary studies that include an experimental part, in the form of an educational intervention with concrete results, are retrieved and retained for analysis; (2) In addition to frequently researched aspects of PAs, such as type, gender, communication modalities, and morphological characteristics, the current review focuses on the educational and pedagogical aspects, including student gains in the cognitive, social/emotional, and metacognitive domains.

Education indeed constitutes a "dynamic complex system" (Tsui and Tavares 2021); therefore, educational technology should be continuously reexamined in light of the new pedagogical approaches, and vice versa. Fawns (2022) pertinently advocates the "entangled education" model, where technology and pedagogy are not competing for precedence; rather, they closely collaborate and proceed hand-in-hand to address the challenges of modern times. The findings of the current survey verify the need for such an alignment between technology and pedagogy and the "mutual shaping of purpose, context, values, methods and tech" (Fawns 2022). It is expected that educationally and pedagogically sound scenarios, combined with high-tech developments such as PAs, will achieve enhanced learning outcomes, a better learning experience, and more positive attitudes among the learners toward the subject taught as well as toward the overall process of learning.

Acknowledgment

The authors wish to thank the Special Account for Research Grants of the University of West Attica, Athens, Greece, for covering the cost of this open access publication.

AI Acknowledgment

The authors declare that generative AI or AI-assisted technologies were not used in any way to prepare, write, or complete essential authoring tasks in this manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

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Appendix: List of Reviewed Papers

The list of the 121 reviewed papers can be accessed at https://drive.google.com/drive/folders/1CoFhekXSBRhThXCM0NRhQCz2_61UvaT_?usp=sharing.

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