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The impact of pedagogical agents' gender on academic learning: a systematic review.

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2 ABSTRACT

3 Virtual learning environments often use virtual characters to facilitate and improve the learning
4 process. These characters, known as pedagogical agents, can take on different roles, such as
5 tutors or companions. Research has highlighted the importance of various characteristics of
6 virtual agents, including their voice or non-verbal behaviors. Little attention has been paid to the
7 gender-specific design of pedagogical agents, although gender has an important influence on the
8 educational process. In this article, we perform an extensive review of the literature regarding the
9 impact of the gender of pedagogical agents on academic outcomes. Based on a detailed review
10 of 59 articles, we analyze the influence of pedagogical agents' gender on students' academic
11 self-evaluations and achievements to answer the following questions: (1) Do students perceive
12 virtual agents differently depending on their own gender and the gender of the agent? (2) Does the
13 gender of pedagogical agents influence students' academic performance and self-evaluations?
14 (3) Are there tasks or academic situations which a male virtual agent is better suited to than
15 a female virtual agent, and vice versa, according to empirical evidence? (4) How do a virtual
16 agent's pedagogical roles impact these results? (5) How do a virtual agent's appearance and
17 interactive capacities impact these results? (6) Are androgynous virtual agents a potential solution
18 to combatting gender stereotypes? This review provides important insight to researchers on how
19 to approach gender when designing pedagogical agents in virtual learning environments.

20 **Keywords:** Virtual Agent, Gender, Pedagogical Agent, Learning Environment, Gender Stereotypes, Systematic Review

1 INTRODUCTION

21 Pedagogical agents are virtual characters in digital environments used to improve learning in educational
22 settings (Mohtadi et al., 2014; Schroeder et al., 2017). They can take on different roles, such as expert,
23 mentor, or motivator (Baylor and Kim, 2005). As shown in a meta-analytic review of 43 studies by
24 Schroeder et al. (2013), pedagogical agents can have a positive effect on students' free recall ability,
25 knowledge retention, and transfer of prior knowledge to new situations or problems. However, some
26 characteristics of pedagogical agents may impact the learning process: for instance, how realistic the
27 virtual agents' appearance is (Baylor and Kim, 2004), the way they communicate with learners, verbally
28 or nonverbally, positively or negatively (Gratch et al., 2007; Pecune et al., 2016), or the way they deliver
29 feedback, using voice, text, or both (Kim and Baylor, 2016).

30 Virtual agents' gender is another feature that users can perceive from the agents' appearance (Lee, 2003).
31 Yet few studies have evaluated the impact of pedagogical agents' gender, which is surprising considering

32 the amount of research in Social Cognition documenting the impact of the gender of both learners and
33 teachers on academic learning. Social Cognition and human-to-human studies are particularly interesting
34 in the domain of virtual agents, as research shows that individuals have a propensity to interact with
35 virtual agents as if they were human (Nass and Moon, 2000). Research in Social Cognition and Cognitive
36 Psychology can therefore be enlightening for understanding users' perception of virtual characters and
37 the effect of these perceptions on their performance. This is why we present some major Social Cognition
38 research on the impact of learners and teachers' gender on learners' academic outcomes. For instance,
39 Sansone (2019) conducted a survey on the link between high school students' beliefs about women's
40 abilities in math and science and their teacher's gender, finding that students were less likely to report that
41 men are better than women in math/science when assigned to female teachers. Teachers' behavior can also
42 impact girls' and boys' learning differently: a large scale survey conducted by Forgasz and Leder (1996)
43 showed that students who perceived their math teachers to be interested in them as individuals were more
44 likely to have functional beliefs about themselves in mathematics, and this was more critical for female
45 learners than male learners. Core beliefs represent general and strongly held views about ourselves, others,
46 and the world; they influence the way we react in different circumstances. Functional beliefs are rational
47 thought patterns which are generally useful for individuals to achieve their goals (Ellis, 1962). In the
48 forementioned study, math teachers' behaviors seemed to favor boys over girls: boys had more interactions
49 with their teachers, teachers were more tolerant of boys' misbehavior, and they had higher expectations of
50 boys (Forgasz and Leder, 1996). A meta-analysis conducted by Lindberg et al. (2010) from 242 studies
51 published between 1990 and 2007 indicated that while male and female learners performed similarly in
52 mathematics, female students reported higher anxiety, more discomfort, and lower interest and self-efficacy
53 in math classes than male students. Parents themselves tend to attribute different explanations for their
54 children's academic performance depending on their gender: they explain their sons' mathematical success
55 as due to their natural talent, whereas they explain their daughters' as due to their effort (Yee and Eccles,
56 1988). These results were replicated by Rätty et al. (2002) who also found that parents of boys evaluated
57 their child's mathematical competence as higher than parents of girls, and parents of girls perceived them
58 as surpassing boys in reading. Despite this, parents still attributed competence in reading as resulting from
59 effort for girls but from natural talent for boys. By explaining their daughters' success in math as due to
60 effort, the authors suggested that parents may undermine both their own and their daughters' estimation
61 of their daughters' success in mathematics, hence raising possible doubts about their future success in a
62 domain that they think gets increasingly complicated; meanwhile, they may encourage boys to develop
63 greater confidence in their future success (Yee and Eccles, 1988).

64 All these differences reflect the influence of gender stereotypes that lead people to consider men to be
65 better at math than women, and women to be better in liberal arts -such as literature, for example- than
66 men. In addition, studies have shown that the fear of being negatively stereotyped in a skill area produces
67 negative thoughts, which in turn reduce individuals' working memory capacity and impair learning and
68 performance (Schmader and Johns, 2003). This phenomenon, called *Stereotype Threat* (Steele and Aronson,
69 1995), applies to different stereotypes and social groups, such as boys in reading tests (Pansu et al., 2016)
70 and girls and women in math tests (Régner et al., 2014). The effects of Stereotype Threat can be reduced
71 using different strategies, such as reading a story about a successful role model before taking a test (Bagès
72 and Martinot, 2011; Bagès et al., 2016).

73 Presenting pedagogical agents as role models could be a potential solution for reducing the effects of
74 Stereotype Threat. Researchers designing agents should take into account the gender of both learners
75 and pedagogical agents to adapt the agent to the learners. The advantages of adapting virtual agents to
76 participants have been demonstrated in several studies. For instance, in Vilaro et al. (2021), participants (all

77 Black women) liked Black female agents for being artificial, hence creating a sense of trust and freedom
78 where participants could avoid inherent biases and racism. In virtual learning environments, research has
79 shown the impact of virtual agents' gender on human-agent interactions (see Section 3.4). However, the
80 gender of *pedagogical* virtual agents is rarely considered as an important characteristic in the design of
81 virtual learning environments, whereas most pedagogical agents are human-like, and their gender can have
82 an impact on academic outcomes (see Section 3.5). In terms of perception, various studies have shown
83 that male virtual agents are rated as more powerful (Nunamaker et al., 2011), more expert (Nunamaker
84 et al., 2011), and more knowledgeable (Baylor and Kim, 2004), whereas female agents are rated as more
85 likable (Nunamaker et al., 2011) and more attractive (Lunardo et al., 2016). These attributes are important
86 in learning environments, as competent and expert agents improve learners' performance (Baylor and
87 Kim, 2004), and likable and attractive agents improve learners' self-perception including their self-efficacy
88 (feeling of achievement) (Rosenberg-Kima et al., 2008), which may help improve their performance (Plant
89 et al., 2009).

90 In this article, we present an extensive state of the art focusing on the *effects of pedagogical agents'*
91 *gender in virtual learning environments*. We explore the impact of gender on the users' perceptions of
92 agents and on their learning.

93 This article is organized as follows. In the next section, we explain our methodology used to conduct
94 the state of the art and particularly how we used the PRISMA method to select relevant articles (Webster
95 and Watson, 2002). In Section 3, the selected articles are summarized in Table 1 and 2 to provide a
96 comprehensive review of research on the impact of pedagogical agents' gender on learners' performance
97 and self-perception in academic domains. We discuss the articles summarized in the tables in Section 3.4
98 and Section 3.5. In Section 3.4, we address research highlighting the impact of virtual agents' gender
99 on users' perceptions. In Section 3.5, we focus on pedagogical agents and the impact of their gender
100 on learners' academic outcomes. The last section discusses what could be done in future research on
101 virtual learning environments to reduce gender stereotypes and to improve learners' performance, and the
102 important research questions that arise from this review.

2 METHODS

103 2.1 Search strategy

104 This article examines research on the impact of virtual agents' gender on learners but also more generally
105 on users' behavior and perceptions. For this purpose, we reviewed articles from the Web of Science
106 database over a twenty-one-year period from 2000 to 2021. To collect the relevant studies, we conducted an
107 online database search with the query *gender+("virtual agent*" OR "virtual character*")*. This systematic
108 review was conducted according to the PRISMA guidelines presented in Figure 1 (Webster and Watson,
109 2002) as follows: (1) scanning databases and starting with the major contributions in the leading journals,
110 (2) reviewing the citations for the articles identified in step 1 to determine prior articles that should be
111 considered, and (3) identifying articles citing the key articles identified in the previous steps. We used
112 Google Scholar for the last step. A total of 120 articles were retained after following these steps.

113 2.2 Selection of articles

114 From this set of articles, we selected empirical studies analyzing the effect of virtual agents' gender
115 on users' perceptions, behaviors, and academic outcomes. We only took into account embodied virtual
116 agents (i.e. we excluded studies on vocal assistants). We focused on Western culture and thus only selected

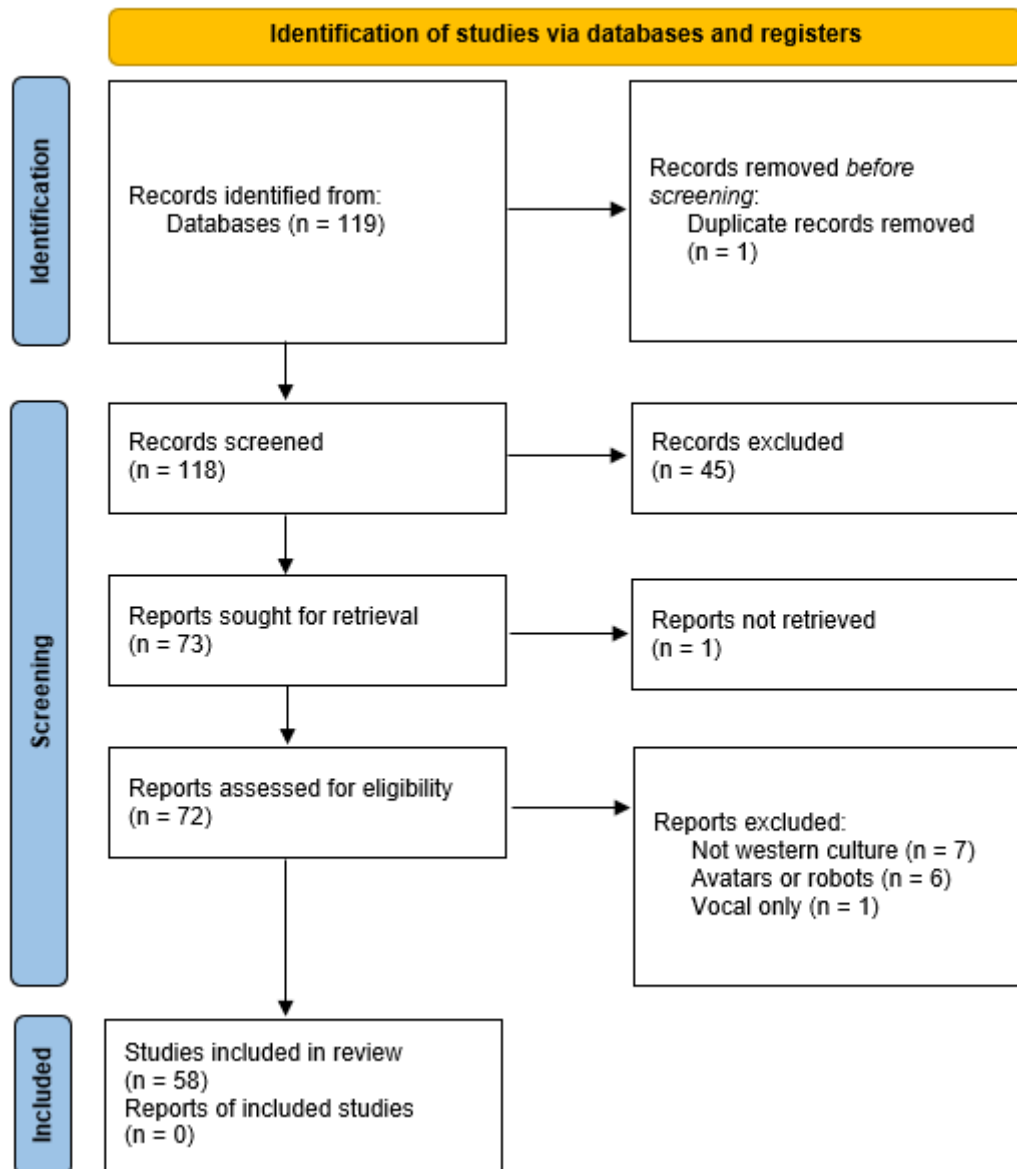


Figure 1. PRISMA 2020 flow diagram for new systematic reviews.

117 papers relating to this culture. We eliminated articles only about avatars (users embodying a virtual agent)
 118 which were mainly about video games. In the end we retained a set of 59 articles. We distinguished two
 119 types of research articles: Perceptive studies of virtual agents depending on their gender, regardless of
 120 the application domain, and research studies on the impact of gendered virtual agents in the context of a
 121 learning task.

122 This systematic review focuses on how virtual agents are designed, and the impact of their gender on
 123 different academic outcomes (motivation, learning, interest), but also on participants' perceptions of the
 124 agents. The research questions guiding this review are as follows:

- 125 1. Do students perceive virtual agents differently depending on their own gender and the gender of the
 126 agent?

- 127 2. Does the gender of pedagogical agents influence students' academic performance and self-evaluations?
- 128 3. Are there tasks or academic situations which a male virtual agent is better suited to than a female
- 129 virtual agent, and vice versa, according to empirical evidence?
- 130 4. How do a virtual agent's pedagogical roles impact these results?
- 131 5. How do a virtual agent's appearance and interactive capacities impact these results?
- 132 6. Are androgynous virtual agents a potential solution to combatting gender stereotypes?

3 SYSTEMATIC REVIEW OF VIRTUAL AGENTS' GENDER AND ITS IMPACT ON USERS' PERCEPTIONS AND ACADEMIC OUTCOMES

133 In this section, we first review the different measures used to assess users' perceptions of agents, users'
134 learning and self-evaluations. We then highlight the persistence of gender stereotypes in human-machine
135 interactions by presenting research on users' perceptions of virtual agents depending on their gender
136 (Section 3.4). Secondly, we focus on pedagogical agents and discuss research that shows the effect of their
137 gender on learners (Section 3.5).

138 3.1 Subjective measures of users' perceptions of agents

139 Most of the studies used post-experience questionnaires to assess users' perceptions of virtual agents.
140 Likert scale items were used to determine participants' stereotyped attributions of the agents, corresponding
141 to communal traits stereotypically associated with women (e.g., affectionate, compassionate, sensitive,
142 inviting, helpful), agency traits stereotypically associated with men (e.g., arrogant, ambitious, aggressive,
143 courageous, and decisive), and competence traits associated more often with men (e.g., knowledgeable,
144 intelligent, expert, credible, creative, innovative and organized) (Lee, 2003; Nunamaker et al., 2011; Feng
145 et al., 2017; Khashe et al., 2017; van der Lubbe and Bosse, 2017; Kantharaju et al., 2018; Sczesny et al.,
146 2018). Another questionnaire was sometimes used to determine which stereotypical gendered traits users
147 applied to the agents (Kulms et al., 2011). This scale, the Bem Sex Role Inventory (BSRI) developed by
148 Bem (1974), measures the construction of the gender schema of individuals, aims to highlight androgyny,
149 and questions the usual dichotomy of female/male gendered traits stereotypically attributed to people. The
150 BSRI consists of 20 positive items stereotypically associated with men (e.g., independent, analytical), 20
151 other positive items stereotypically associated with women (e.g., compassionate, loves children), and 20
152 other positive neutral items (e.g., tactful, reliable). The agents' gender perception was evaluated with a 5-
153 point Likert sliding scale, for example with men=1, androgynous=4, and women=7 (Lee, 2003; McDonnell
154 et al., 2009; Niculescu et al., 2009; Nag and Yalçın, 2020). Other social attitude perceptions were also
155 assessed with Likert scale items, such as the perceived friendliness, trustworthiness, likability, and social
156 presence of the agent (Lee, 2003; Guadagno et al., 2007; Nunamaker et al., 2011; Lunardo et al., 2016;
157 Khashe et al., 2017; Akbar et al., 2018). Social presence is particularly important as it provides individuals
158 with the possibility of developing a relationship or having a social interaction with one another, as they
159 recognize each other as "social beings" (Biocca et al., 2003). Social presence is commonly defined as
160 the sensation of being in the presence of a real person and having access to their feelings (Biocca, 1997),
161 and can be assessed with a 5-item survey (e.g. "I feel that the person is watching me and is aware of my
162 presence") (Bailenson et al., 2001) and the Networked Minds Questionnaire (e.g. "The other individual
163 didn't notice me in the room") (Biocca et al., 2001), as used by Kulms et al. (2011).

164 3.2 Objective measures of learning

165 The impact of pedagogical agents on users' learning can be assessed by measuring users' performance
166 in an exercise by comparing different conditions: for example, virtual agents with different behaviors
167 (Chang et al., 2019), the presence of gendered virtual agents (Kim and Wei, 2011), or virtual agents with
168 different genders (Kim, 2013). Performance can be measured with different problem-solving tests: using
169 knowledge retention (using past knowledge to solve a problem, Sajjadi et al., 2020), recall (the ability
170 to remember items, Wirzberger et al., 2019), or transfer learning (using past knowledge to solve new
171 problems, Makransky et al., 2019). In addition to performance, researchers can also evaluate response times
172 and effort. Effort can be measured by comparing the number of problems solved (that are not necessarily
173 correct) in different problem-solving tests (Krämer et al., 2016). Response times correspond to the duration
174 required to solve a problem (Hayes et al., 2010).

175 3.3 Users' self-evaluations

176 In learning situations, other more subjective measures than performance are rated using Likert-scale items.
177 These measures include the interest in a task or a domain, (e.g., "I will take a hard sciences course as an
178 elective", Rosenberg-Kima et al., 2008), beliefs about the utility of a task or a domain (e.g., "I would have
179 many good career opportunities if I was a hard science major", Plant et al., 2009), learners' self-efficacy as
180 in feeling capable of performing a task (e.g., "I can achieve high grades in math", Kim and Wei, 2011),
181 learners' self-regulation to regulate their behaviors to succeed in a task (e.g., "I kept track of my progress",
182 Baylor and Kim, 2004), learners' motivation assessed with the Situational Motivation Scale (SIMS) (Guay
183 et al., 2000) which includes 16 items about the motivation to work on tasks (e.g., "Because I am doing it for
184 my own good", Krämer et al., 2016), learners' enjoyment (e.g., "How much did you enjoy preparing for the
185 exam?", Shiban et al., 2015), their perceived learning effectiveness (e.g., "I gained a good understanding
186 of the basic concepts of the materials", Sajjadi et al., 2020), and their mental demand to know how much
187 mental and perceptual activity was required (thinking, deciding, calculating, etc.), e.g., "Was the task easy
188 or demanding?" (Hart and Staveland, 1988; Pezzullo et al., 2017).

189 3.4 Evidence of the persistence of gender stereotypes in human-machine interactions

190 We have summarized the selected studies on users' perceptions of virtual agents depending on their
191 gender in each line of the following table. We stated agents' characteristics, number of male and female
192 participants with their average age, tasks of the study, the observed measures and the study's results. Some
193 acronyms are present in this table. We used MA for Male Agent(s) and FA for Female Agent(s). In the
194 same logic, MP is used for Male Participant(s), and FP for Female Participant(s).

Table 1 Summary of articles on perceptive studies of virtual agents depending on their gender, regardless of the application domain. Articles are listed from oldest to most recent. FA = female agent, MA = male agent, FP = female participants, MP = male participants. The agents column describes the number of agents depending on their gender, their dimension (2-D or 3-D), their appearance (realist or cartoon), and their role. The participants column describes the number of men and women who participated in the study, and the average age. In the result(s) column, “MP > FP” means it impacted more the male participants than the female participants. “FA > MA” means the female agent has more impact than the male agent. Explanations are in section 3.4.

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(Lee, 2003)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 2-D • Text • Cartoon • Adviser 	<ul style="list-style-type: none"> • 28 MP • 88 FP • avg age N/A 	Playing a multiple-choice game with an agent. Participants could change their answer after they were told the agent's answer. It was specified that the agent's answer might not be correct.	<ul style="list-style-type: none"> • Masculinity • Attractiveness • Competence • Trustworthiness • Persuasiveness (sport or fashion questions) 	<ul style="list-style-type: none"> • <i>Masculinity</i>: MA > FA • <i>Attractiveness, competence</i>: FA > MA • <i>Persuasiveness (sport)</i>: MA > FA • <i>Persuasiveness (fashion)</i>: FA > MA
(Zanbaka et al., 2006)	<ul style="list-style-type: none"> • 2 MA • 2 FA • 3-D • Voice • Realist • Speaker 	<ul style="list-style-type: none"> • 41 MP • 97 FP • avg age 20.6 	Listening to agents deliver a message to change participants' attitudes about university-wide comprehensive exams.	<ul style="list-style-type: none"> • Persuasiveness 	<ul style="list-style-type: none"> • <i>Persuasiveness</i>: - MP: FA > MA - FP: MA > FA
(Guadagno et al., 2007)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 1 neutral • 3-D • Voice • Realist • Speaker 	<ul style="list-style-type: none"> • 37 MP • 29 FP • avg age N/A 	Listening to agents talk about changes to university security policy.	<ul style="list-style-type: none"> • Likeability • Credibility • Presentation quality • Persuasiveness 	<ul style="list-style-type: none"> • <i>Likeability, credibility, presentation quality</i>: - MP: not significant - FP: FA > MA • <i>Persuasiveness</i>: - MP: MA > FA - FP: FA > MA
(Guadagno et al., 2007)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 3-D • Voice • Realist • Speaker 	<ul style="list-style-type: none"> • 85 MP • 89 FP • avg age N/A 	Listening to agents talk about changes to university security policy.	<ul style="list-style-type: none"> • Likeability • Credibility • Presentation quality • Social presence • Persuasiveness 	<ul style="list-style-type: none"> • <i>Likeability</i>: FA > MA • <i>Credibility, presentation quality</i>: not significant • <i>Persuasiveness</i>: - MP: MA > FA - FP: not significant

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(Gulz et al., 2007)	<ul style="list-style-type: none"> • 2 MA • 2 FA • 2-D • Voice • Realist • Presenter 	<ul style="list-style-type: none"> • 72 MP • 86 FP • avg age N/A 	Listening to agents present university program engineering.	<ul style="list-style-type: none"> • Favorite agent • Interest 	<ul style="list-style-type: none"> • <i>Favorite agent:</i> <ul style="list-style-type: none"> - MP: less feminine & less masculine agents > more masculine agent > more feminine agent - FP: less feminine & less masculine agents > more feminine agent > more masculine agent • <i>Interest:</i> <ul style="list-style-type: none"> - MP: more feminine & more masculine agents > less feminine & less masculine agents - FP: more feminine & more masculine & less feminine agents > less masculine agent
(Dill et al., 2008)	<ul style="list-style-type: none"> • 16 MA • 16 FA • 3-D • Realist • Video game characters 	<ul style="list-style-type: none"> • 61 MP • 120 FP • avg age 18.82 	Watching a PowerPoint presentation opposing still pictures of video game characters and male or female US senators. Reading a real-life story about the sexual harassment of a female student by a male professor.	<ul style="list-style-type: none"> • Tolerance for sexual harassment • Rape-supportive attitudes 	<ul style="list-style-type: none"> • <i>Tolerance for sexual harassment:</i> MP > FP • <i>Rape-supportive attitudes:</i> MP > FP
(Rosenberg-Kima et al., 2008)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 3-D • Voice • Realist • Speaker 	<ul style="list-style-type: none"> • 89 FP • avg age 19.7 	Listening to an agent describe four female engineers and the benefits of engineering, with or without the agent present.	<ul style="list-style-type: none"> • Interest • Self-efficacy • Utility for engineering 	<ul style="list-style-type: none"> • <i>Interest, self-efficacy, utility for engineering:</i> not significant

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(Rosenberg-Kima et al., 2008)	<ul style="list-style-type: none"> • 4 MA • 4 FA • 3-D • Voice • Realist • Speaker 	<ul style="list-style-type: none"> • 111 FP • avg age 19.72 	Listening to an agent describe four female engineers and the benefits of engineering, with or without the agent present.	<ul style="list-style-type: none"> • Utility for engineering • Fewer engineering gender stereotypes 	<ul style="list-style-type: none"> • <i>Utility for engineering:</i> MA > FA (not significant) • <i>Fewer engineering gender stereotypes:</i> FA > MA
(Niculescu et al., 2009)	<ul style="list-style-type: none"> • 3 MA • 3 FA • 1 neutral • 3-D • Voice • Cartoon • Assistant 	<ul style="list-style-type: none"> • 24 MP • 24 FP • avg age N/A 	Interacting with agents about medical queries, evaluating an androgynous agent's gender either after or before rating non-androgynous agents.	<ul style="list-style-type: none"> • Androgynous agent's perceived gender 	<ul style="list-style-type: none"> • <i>Androgynous agent's perceived gender:</i> <ul style="list-style-type: none"> - Non-androgynous agents rated first: <ul style="list-style-type: none"> - FP: more feminine - MP: more masculine - Androgynous agent rated first: <ul style="list-style-type: none"> - FP: more masculine - MP: more feminine
(McDonnell et al., 2009)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 2 neutral • 3-D • Realist • Subject 	<ul style="list-style-type: none"> • 22 MP • 19 FP • avg age N/A 	Watching a video of agents walking.	<ul style="list-style-type: none"> • Agents' perceived gender 	<ul style="list-style-type: none"> • <i>Agents' perceived gender:</i> <ul style="list-style-type: none"> - FA (male walk): ambiguous - FA (neutral walk): female - MA (female walk): ambiguous - MA (neutral walk): male - Genderless agents: ambiguous - Genderless agents (female walk): female - Genderless agents (male walk): male - Genderless agents (neutral walk): female

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(McDonnell et al., 2009)	<ul style="list-style-type: none"> • 3 MA • 3 FA • 3-D • Realist • Subject 	<ul style="list-style-type: none"> • 33 MP • 5 FP • avg age N/A 	Watching a video of agents walking.	<ul style="list-style-type: none"> • Agents' perceived gender 	<ul style="list-style-type: none"> • <i>Agents' perceived gender:</i> <ul style="list-style-type: none"> - FA rated 'most female': FA (bigger hips and breast size) > FA (smallest hips and breast size) - MA rated 'most male': no difference - Agents rated 'most ambiguous': FA (male walk) & MA (female walk)
(Fox and Bailenson, 2009)	<ul style="list-style-type: none"> • 4 FA • 3-D • Realist • Subject 	<ul style="list-style-type: none"> • 43 MP • 40 FP • avg age 20.82 	Participants encountered an agent (low gaze (LG) or high gaze (HG), masculine or feminine clothes) via virtual reality, then made judgments about them.	<ul style="list-style-type: none"> • Rape myth acceptance • Benevolent sexism • Hostile sexism 	<ul style="list-style-type: none"> • <i>Rape myth acceptance:</i> masculine LG agent > feminine HG agent > masculine HG agent > feminine LG agent • <i>Benevolent sexism:</i> masculine LG agent > feminine LG agent > masculine HG agent • <i>Benevolent sexism:</i> LG agent > HG agent • <i>Hostile sexism:</i> feminine HG agent > masculine HG agent

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(Cloud-Buckner et al., 2009)	<ul style="list-style-type: none"> • 2 MA • 2 FA • 3-D • Voice • Realist • Guide 	<ul style="list-style-type: none"> • 19 MP • 16 FP • avg age N/A 	Watching an agent introducing a college campus as an online tour guide.	<ul style="list-style-type: none"> • Friendliness • Anger • Cooperation • Self consciousness • Adventurousness • Sympathy • Sociability • Assertiveness • Cooperation • Self consciousness • Self discipline 	<ul style="list-style-type: none"> • <i>Friendliness, anger, cooperation, self consciousness, adventurousness, sympathy:</i> Outgoing personality: MA > FA • <i>Sociability, assertiveness, cooperation, self consciousness, self discipline:</i> Introverted personality: FA > MA
(Niculescu et al., 2010)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 1 neutral • 3-D • Text • Cartoon • Tutor 	<ul style="list-style-type: none"> • 4 MP • 4 FP • avg age N/A 	Asking an agent medical questions.	<ul style="list-style-type: none"> • Comfortable • Confident • Less tense • Preferred agent 	<ul style="list-style-type: none"> • <i>Comfortable, confident, less tense:</i> FA > MA & androgynous agent • <i>Preferred agent:</i> FA > MA > androgynous agent
(Rosenberg-Kima et al., 2010)	<ul style="list-style-type: none"> • 2 MA • 2 FA • 3-D • Voice • Realist • Speaker 	<ul style="list-style-type: none"> • 119 FP • avg age 21.49 	Listening to an agent describe four female engineers and the benefits of engineering.	<ul style="list-style-type: none"> • Interest • Self-efficacy • Utility • Agent's likeability • Fewer engineering gender stereotypes 	<ul style="list-style-type: none"> • <i>Interest:</i> - Black FP: Black FA > others - White FP: FA > MA • <i>Self-efficacy, utility, agent's likeability:</i> - Black FP (Black agents): FA > MA - Black FP (White agents): MA > FA • <i>Fewer engineering gender stereotypes:</i> - Black FP: Black agents > White agents - White FP: FA > MA

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(Astrid et al., 2010)	<ul style="list-style-type: none"> • 1 FA • 3-D • Voice • Realist • Questioner 	<ul style="list-style-type: none"> • 41 MP • 42 FP • avg age 37.27 	Answering personal questions from an agent.	<ul style="list-style-type: none"> • Weak • Shy • Naive • Compassionate • Inviting 	<ul style="list-style-type: none"> • <i>Weak, shy, naive, compassionate, inviting</i>: not significant
(Nunamaker et al., 2011)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 3-D • Voice • Realist • Questioner 	<ul style="list-style-type: none"> • 53 MP • 35 FP • avg age 25.45 	Answering questions from an agent simulating an airport screening.	<ul style="list-style-type: none"> • Power • Trustworthiness • Expertise • Likability 	<ul style="list-style-type: none"> • <i>Power, trustworthiness, expertise</i>: MA > FA • <i>Likability</i>: FA > MA
(Kulms et al., 2011)	<ul style="list-style-type: none"> • 2 MA • 2 FA • 3-D • Voice • Realist • Questioner 	<ul style="list-style-type: none"> • 32 MP • 40 FP • avg age 35.03 	Answering casual questions asked by an agent, either in a low gaze (LG) or a high gaze (HG) condition.	<ul style="list-style-type: none"> • Masculinity • Positive evaluation • Social presence 	<ul style="list-style-type: none"> • <i>Masculinity</i>: HG MA > LG MA • <i>Positive evaluation</i>: FA > MA • <i>Social presence</i>: MA > FA
(Brahnam and De Angeli, 2012)	<ul style="list-style-type: none"> • 8 MA • 8 FA • 3 neutral • 2-D • Text • Cartoon • Chatbot 	<ul style="list-style-type: none"> • 127 MP • 73 FP • avg age N/A 	Chatting over text with a chatbot.	<ul style="list-style-type: none"> • Sexual discourse • Avg number of words about money/job, and physical appearance 	<ul style="list-style-type: none"> • <i>Sexual discourse, avg number of words (physical appearance)</i>: FA > MA • <i>Avg number of words (money/jobs)</i>: MA > FA (among adult agents)
(Ozogul et al., 2013)	<ul style="list-style-type: none"> • 2 MA • 2 FA • 3-D • Cartoon • Tutor 	<ul style="list-style-type: none"> • 35 MP • 42 FP • avg age 12.83 	Rating pictures of agents.	<ul style="list-style-type: none"> • Gender preference • Preferred agent to learn about engineering from 	<ul style="list-style-type: none"> • <i>Gender preference</i>: <ul style="list-style-type: none"> - FP: FA > MA - MP: MA > FA • <i>Preferred agent to learn about engineering from</i>: young FA > young MA > old MA > old FA

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(Payne et al., 2013)	<ul style="list-style-type: none"> • 4 MA • 4 FA • 2-D & 3-D • Cartoon • Assistant 	<ul style="list-style-type: none"> • 220 MP • 358 FP • avg age 35.56 	Choosing an agent to assist in self-service checkouts.	<ul style="list-style-type: none"> • Preferred agent 	<ul style="list-style-type: none"> • <i>Preferred agent:</i> - FP: FA > MA - MP: MA > FA
(Lunardo et al., 2016)	<ul style="list-style-type: none"> • 2 MA • 2 FA • 2-D • Text • Realist • Assistant 	<ul style="list-style-type: none"> • 107 MP • 147 FP • avg age N/A 	Interacting with an agent over text at fnac.com.	<ul style="list-style-type: none"> • Attractiveness 	<ul style="list-style-type: none"> • <i>Attractiveness:</i> - Agents (corporate clothes): FA > MA - Agents (casual clothes): FA > MA (not significant)
(van der Lubbe and Bosse, 2017)	<ul style="list-style-type: none"> • 2 MA • 2 FA • 3-D • Voice • Realist • Employee 	<ul style="list-style-type: none"> • 55 MP • 38 FP • avg age N/A 	Interacting with an agent employee to negotiate the agent's salary (assertive agent or non-assertive agent).	<ul style="list-style-type: none"> • Appropriate language • Sensitive • No deal reached • Persuasiveness 	<ul style="list-style-type: none"> • <i>Appropriate language:</i> assertive FA > assertive MA • <i>Sensitive:</i> non-assertive MA > non-assertive FA • <i>No deal reached:</i> assertive MA > assertive FA > non-assertive FA > non-assertive MA (not significant) • <i>Persuasiveness:</i> assertive FA > assertive MA
(Feng et al., 2017)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 3-D • Voice • Realist • Instructor 	<ul style="list-style-type: none"> • 31 MP • 32 FP • avg age 21.37 	Acting out a scene in presence of an agent giving negative feedback.	<ul style="list-style-type: none"> • Inspiration • Self-blame • Helpfulness • Preferred agent 	<ul style="list-style-type: none"> • <i>Inspiration, self-blame, helpfulness, preferred agent:</i> FA > MA

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(Mell et al., 2017)	<ul style="list-style-type: none"> • 1 FA • 2-D • Text • Realist • Assistant 	<ul style="list-style-type: none"> • 241 MP • 140 FP • avg age 35.13 	Answering questions from a chatbot about sensitive information, either with a picture of a real woman, a picture of a female virtual agent, or no picture.	<ul style="list-style-type: none"> • Reported lies • Allowing the system to do a credit check • Providing their address 	<ul style="list-style-type: none"> • <i>Reported lies</i>: human > no presence > agent • <i>Allowing the system to do a credit check</i>: <ul style="list-style-type: none"> - FP: agent > human > no presence - MP: no presence > agent > human • <i>Providing their address</i>: <ul style="list-style-type: none"> - FP: equal across conditions - MP: human > agent > no presence
(Khashe et al., 2017)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 3-D • Voice • Realist • Speaker 	<ul style="list-style-type: none"> • 98 MP • 116 FP • avg age N/A 	Requested to switch off the lights and open the window by a manager, either voice only, text only, or a virtual agent).	<ul style="list-style-type: none"> • Affectionate • Friendly • Likable • Persuasiveness 	<ul style="list-style-type: none"> • <i>Affectionate, friendly, likable</i>: female (agent and voice only) > male (agent and voice only) • <i>Persuasiveness</i>: female (agent, voice only, text only) > male (agent, voice only, text only)
(Kantharaju et al., 2018)	<ul style="list-style-type: none"> • 2 MA • 2 FA • 3-D • Voice • Realist • 2 experts • 2 motivators 	<ul style="list-style-type: none"> • 113 MP • 92 FP • avg age N/A 	Listening to a persuasive conversation about cinema between agents.	<ul style="list-style-type: none"> • Distant • Arrogant • Forceful • Credible • Persuasiveness 	<ul style="list-style-type: none"> • <i>Distant, arrogant, forceful, credible, persuasiveness</i>: MP > FP
(Akbar et al., 2018)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 3-D • Text • Realist • Interviewer 	<ul style="list-style-type: none"> • 158 MP • 158 FP • avg age N/A 	Interviewed by an agent over text for a job in a financial firm.	<ul style="list-style-type: none"> • Agreeableness • Trustworthiness 	<ul style="list-style-type: none"> • <i>Agreeableness</i>: opposite gender agent > matching-gender agent • <i>Trustworthiness</i>: matching-gender agent > opposite gender agent

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(Mousas et al., 2018)	<ul style="list-style-type: none"> • 2 MA • 3-D • Realist • Subject 	<ul style="list-style-type: none"> • 56 MP • 16 FP • avg age 23.24 	Answering questions about the agents (e.g., "Would you feel uneasy if this virtual character communicated with you?") by the experimenter while the agent walked towards the participant.	<ul style="list-style-type: none"> • Easiness • Comfortableness • Readiness for interaction • Likeability 	<ul style="list-style-type: none"> • <i>Easiness, comfortableness, readiness for interaction</i>: MP > FP • <i>Likeability</i>: <ul style="list-style-type: none"> - zombie agent: MP > FP - MA: not significant
(Ait Challal and Grynszpan, 2018)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 3-D • Realist • Subject 	<ul style="list-style-type: none"> • 12 MP • 12 FP • avg age 23.6 	Watched virtual agents sit in front of them (in gaze following, gaze avoidance, high direct gaze, and low direct gaze conditions). Judging their personalities.	<ul style="list-style-type: none"> • Neuroticism • Agreeableness 	<ul style="list-style-type: none"> • <i>Neuroticism</i>: FA > MA • <i>Agreeableness (high direct gaze condition)</i>: MA > FA
(ter Stal et al., 2020)	<ul style="list-style-type: none"> • 4 MA • 4 FA • 2-D • Cartoon • 4 experts, 4 peers 	<ul style="list-style-type: none"> • 67 MP • 69 FP • avg age 51.36 	Observing and rating 8 agents.	<ul style="list-style-type: none"> • Friendliness • Expertise • Authority 	<ul style="list-style-type: none"> • <i>Friendliness</i>: FA > MA • <i>Expertise, authority</i>: MA > FA
(ter Stal et al., 2020)	<ul style="list-style-type: none"> • 4 MA • 4 FA • 2-D • Cartoon • 4 experts, 4 peers 	<ul style="list-style-type: none"> • 35 MP • 30 FP • avg age 67.85 	Observing and rating 8 agents.	<ul style="list-style-type: none"> • Friendliness • Authority 	<ul style="list-style-type: none"> • <i>Friendliness</i>: not significant • <i>Authority</i>: MA > FA
(Zibrek et al., 2020)	<ul style="list-style-type: none"> • 2 neutral • 3-D • Realist • Subject 	<ul style="list-style-type: none"> • 10 MP • 10 FP • avg age N/A 	Pressing a button as soon as they felt uncomfortable with the distance between themselves and an agent walking towards them.	<ul style="list-style-type: none"> • Genderless agents' perceived gender 	<ul style="list-style-type: none"> • <i>Genderless agents' perceived gender</i>: <ul style="list-style-type: none"> - female motions = female - male motions = male

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(Richards et al., 2020)	<ul style="list-style-type: none"> • 6 MA • 6 FA • 3-D • Voice • Realist • Assistant 	<ul style="list-style-type: none"> • 43 MP • 146 FP • avg age 21.7 	Watching 12 videos of 12 different agents introducing themselves.	<ul style="list-style-type: none"> • Favorite agent (before and after watching the videos) 	<ul style="list-style-type: none"> • <i>Favorite agent (before):</i> <ul style="list-style-type: none"> - FP: gender does not matter > FA > MA - MP: gender does not matter > MA > FA • <i>Favorite agent (after):</i> <ul style="list-style-type: none"> Mediterranean FA > Asian FA > White FA
(Nag and Yalçın, 2020)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 1 neutral • 3-D • Realist • Subject 	<ul style="list-style-type: none"> • 41 MP • 31 FP • avg age 21.7 	Looking at pictures of agents and rating them.	<ul style="list-style-type: none"> • Communion • Agency • Competence 	<ul style="list-style-type: none"> • <i>Communion:</i> FA > MA (not significant) • <i>Agency, competence:</i> not significant
(Esposito et al., 2021)	<ul style="list-style-type: none"> • 2 MA • 2 FA • 3-D • Voice • Realist • Assistant 	<ul style="list-style-type: none"> • 22 MP • 24 FP • avg age 71.59 	Watching a video of an agent talking about daycare facilities for the elderly.	<ul style="list-style-type: none"> • Willingness to interact with the agent • Attractiveness • Usefulness • Presentable • Professional • Of good taste • Pleasant • Original • Creative • Captivating 	<ul style="list-style-type: none"> • <i>Willingness to interact with the agent, attractiveness, usefulness, presentable, professional, of good taste, pleasant, original, creative, captivating:</i> FA > MA

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(Esposito et al., 2021)	<ul style="list-style-type: none"> • 2 MA • 2 FA • 3-D • Voice • Realist • Assistant 	<ul style="list-style-type: none"> • 20 MP • 25 FP • avg age 71.22 	Watching a video of an agent talking about daycare facilities for the elderly. (2 nd experiment).	<ul style="list-style-type: none"> • Willingness to interact with the agent • Attractiveness • Usefulness • Presentable • Professional • Of good taste • Pleasant • Original • Creative • Captivating 	<ul style="list-style-type: none"> • <i>Presentable, professional, of good taste, pleasant</i>: FA > MA • <i>Willingness to interact with the agent, attractiveness, usefulness, original, creative, captivating</i>: Not significant
(Vilaro et al., 2021)	<ul style="list-style-type: none"> • 3 FA • 3-D • Voice, text • Realist • Assistant, expert 	<ul style="list-style-type: none"> • 53 FP • avg age 60.90 	Watching an agent deliver colorectal cancer screening messages.	<ul style="list-style-type: none"> • Trustworthiness • Expertise 	<ul style="list-style-type: none"> • <i>Trustworthiness</i>: not significant • <i>Expertise</i>: agents (white medical coat) > agent (casual clothes)
(Antonio Gómez-Jáuregui et al., 2021)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 3-D • Voice • Realist • Interviewer 	<ul style="list-style-type: none"> • 16 MP • 16 FP • avg age 29.95 	Introducing themselves to a blurred-face virtual agent for a job interview.	<ul style="list-style-type: none"> • Dominance • Warmth 	<ul style="list-style-type: none"> • <i>Dominance</i>: not significant • <i>Warmth</i>: FA (mirrored movements) > FA (random movements)

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(Świdrak et al., 2021)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 3-D • Voice • Realist • Player 	<ul style="list-style-type: none"> • 15 MP • 19 FP • avg age 25 	Playing a negotiation/ decision-making game with a female and a male agent.	<ul style="list-style-type: none"> • Touch pleasantness • Touch awkwardness • Touch adequacy • Persuasiveness 	<ul style="list-style-type: none"> • <i>Touch pleasantness</i>: FA > MA • <i>Touch awkwardness</i>: FP > MP • <i>Touch adequacy</i>: FA perceived as more masculine > FA perceived as less masculine • <i>Persuasiveness</i>: <ul style="list-style-type: none"> - MP: agents perceived as more masculine > agents perceived as less masculine - FP: depends on the offer
(Świdrak et al., 2021)	<ul style="list-style-type: none"> • 2 MA • 2 FA • 3-D • Voice • Realist • Player 	<ul style="list-style-type: none"> • 40 MP • avg age 23 	Playing a negotiation/ decision-making game with two female and two male agents.	<ul style="list-style-type: none"> • Masculinity • Touch pleasantness • Touch awkwardness • Touch adequacy • Persuasiveness 	<ul style="list-style-type: none"> • <i>Masculinity</i>: masculine FA > feminine MA • <i>Touch pleasantness</i>: FA > feminine MA • <i>Touch awkwardness</i>: feminine MA > others (not significant) • <i>Touch adequacy</i>: others > feminine MA (not significant) • <i>Persuasiveness</i>: masculine-perceived agents > feminine-perceived agents

195 The studies presented in Table 1 show that gender stereotypes persist in human-machine interactions.
196 Users' behavior varies according to the gendered appearance of virtual agents. For example, in De Angeli
197 and Brahnham (2006), the female virtual agent received a number of violent sexual propositions and
198 even rape threats; the male virtual agent received only a few sexual propositions, none of them violent
199 ("gently presses my lips to yours into a small kiss"), and the other sexual comments made during the
200 interactions with the male virtual agent targeted his girlfriend. In a similar study by Brahnham and De Angeli
201 (2012), users interacted with several pairs of female/male agents, including child agents, White agents,
202 Black agents, and 'old' agents. The female agents were the target of significantly more sexual discourse,
203 comments on their appearance, and swear words than the male agents; this was even true for the pair of
204 child agents. Other features of agents influenced the conversational topics, such as their age and appearance:
205 users talked more about jobs, achievement and money with old agents dressed in formal clothing than with
206 any other pair of agents. However, gender stereotypes still applied to this category, since users interacted
207 more with the older male agent about these topics than with the older female agent.

208 An agent's gender also has a direct influence on participants' decisions. For instance, Lee (2003) reported
209 that users followed more advice from virtual agents when their gender stereotypically matched the topic
210 (e.g., a female agent and cosmetics, a male agent and sports). In this study, the female virtual agent
211 presented as particularly feminine. This result should thus be verified in a separate study using a female
212 virtual agent presenting a sport-oriented appearance to determine whether these results are due solely to
213 gender and not to the agents' presentation (clothes and make-up). In Guadagno et al. (2007), the male
214 virtual agent was more persuasive when perceived to be computer-controlled rather than human-controlled.
215 The opposite was true for the female virtual agent. The authors concluded that these results may have been
216 due to gender stereotypes, specifically by the "participants' expectations for interacting with a computer
217 being more consistent with masculine stereotypes (e.g., competent), whereas expectations for interacting
218 with a human are more consistent with feminine stereotypes (e.g., warm)."Not only the gender of a virtual
219 agent but even their perceived masculinity can influence participants' decisions. In a decision-making game
220 where virtual agents made a monetary offer to male participants, the number of offers accepted were higher
221 with the agents perceived as more masculine (Świdrak et al., 2021). The same results were obtained in a
222 similar study for male participants; in contrast, female participants accepted more offers from the agents
223 than male participants but were only influenced by the offer itself, not by the agents' perceived masculinity
224 (Świdrak et al., 2021).

225 An agent's gender also has an impact on how users perceive the agent in terms of stereotypical traits
226 attributed to men and women (Sczesny et al., 2018). In a study by Nunamaker et al. (2011), the male agent
227 was perceived as more powerful, whereas the female agent was perceived as more likable. Even when
228 male and female agents wore the same clothes, exhibited the same verbal and non-verbal behaviors, and
229 had their faces blurred (thus lacking salient indicators of gender), the female agent was rated higher for
230 warmth than the male agent; however, they were rated similarly for dominance, a trait typically associated
231 with men (Antonio Gómez-Jáuregui et al., 2021). In contrast Kulms et al. (2011), found in their main
232 experiment that participants did not ascribe more masculine traits to the male agents nor more feminine
233 traits to the female agents, unlike in their pretest with 14 participants using still pictures of the same virtual
234 agents. The authors concluded that stereotyped attributions became less important when participants could
235 interpret the behavior of the agents. However, a study by Ait Challal and Grynszpan (2018) contradicts this
236 conclusion: the female agent was rated as less agreeable than the male agent when using high direct gaze.
237 The authors suggested that participants were less tolerant of dominance when expressed by a female agent.
238 Gender stereotypes associated with users' gender can also impact the ratings of virtual agents. In a study
239 by Mousas et al. (2018), male participants reported feeling more at ease and comfortable with a zombie

240 agent than female participants; they also liked the zombie agent more than the female participants did. The
241 authors concluded that gender stereotypes may have influenced the results, because stereotypes call for
242 men to be calmer in the face of fear and embarrassment/disgust and to report milder emotional reactions.

243 Contexts stereotypically associated with one gender may also have an impact on participants' preferences
244 as to the gender of agents: in two experiments conducted by ter Stal et al. (2020), elderly participants
245 preferred still pictures of female agents in a healthcare context. According to the authors, this result
246 could be due to the task - health coaching - being associated with female gender stereotypes. In addition,
247 male agents were rated as more authoritarian and expert than female agents. In a study by Gulz et al.
248 (2007), when virtual agents presented university programs in computer engineering, participants' interest
249 was higher with feminine and masculine agents as compared to 'neutral' agents (a less feminine female
250 agent and a less masculine male agent). However, participants who ranked the less feminine female
251 agent as the best presenter chose her because they believed that she could make more girls interested in
252 computer engineering ("she seems young and nice, and I think she would make more girls interested");
253 and participants who ranked the feminine female agent as the worst presenter chose her because she was
254 a woman who did not seem to belong in that context ("as I said, a woman feels more welcoming than a
255 man, but she looked so styled, which I don't like"). These results show that gender stereotypes apply to the
256 appearance of female agents.

257 In addition to context, agents' roles can also influence how users perceive them. When female agents
258 were presented as assistants to elderly people in their daily life, participants found them to be more worth
259 interacting with, more useful, efficient and well designed, and more captivating, exciting, engaging and
260 attractive than male agents (Esposito et al., 2021). However, in a similar experiment with silent agents, the
261 agents' gender did not affect the participants in terms of the same criteria (Esposito et al., 2021). Voices
262 could have influenced the perceived agents' masculinity/femininity, but this was not measured in the studies.
263 In a different study, expert agents were rated as more credible than motivational agents regardless of their
264 gender (Kantharaju et al., 2018).

265 However, a recent study by Nag and Yalçın (2020) contradicts previous research on how humans perceive
266 virtual agents depending on their gender: still pictures of male and female agents were generally rated
267 similarly for agency (traits typically associated with men: *ambitious, aggressive, courageous, decisive*)
268 and *competence* (traits typically associated with men: *creative, intelligent, innovative, organized*), but not
269 for *communion* (traits typically associated with women: *affectionate, compassionate, sensitive, inviting,*
270 *helpful*) where female agents were rated higher. A limitation of this study is that the female and male
271 agents were quite similar in appearance. This being said, the results of the study tend to be coherent
272 with the evolution of gender stereotypes reported by Eagly et al. (2020) for the perception of *agency* and
273 *competence* traits perception in interpersonal interactions: the gap in *agency* and *competence* in favor of
274 men has reduced. However, the *communion* traits are still largely attributed to women. This raises the
275 question of whether the evolution in the perception of stereotypes in human-human interactions shown by
276 Eagly et al. (2020) can be observed similarly in human-virtual agent interactions.

277 Based on the research presented above, it seems that male virtual agents are perceived as more competent,
278 especially regarding stereotypically male-related topics. They appear as better suited to represent a
279 pedagogical virtual tutor in STEM fields (Science, Technology, Engineering, and Mathematics), since
280 these fields are perceived as masculine (Makarova et al., 2019). In the next section, we focus more
281 specifically on research on pedagogical agents and the impact of their gender on users' academic outcomes.

282 3.5 The effect of virtual agents' gender on academic outcomes

283 We have summarized the selected studies on the impact of gendered virtual agents in the context of a
284 learning task in each line of the following table. We stated agents' characteristics, number of male and
285 female participants with their average age, tasks of the study, the observed measures and the study's results.
286 Some acronyms are present in this table. We used MA for Male Agent(s) and FA for Female Agent(s). In
287 the same logic, MP is used for Male Participant(s), and FP for Female Participant(s).

Table 2 Summary of research studies on the impact of gendered virtual agents in the context of a learning task. Articles are listed from oldest to most recent. FA = female agent, MA = male agent, FP = female participants, MP = male participants. The agents column describes the number of agents depending on their gender, their dimension (2-D or 3-D), their appearance (realist or cartoon), and their role. The participants column describes the number of men and women who participated in the study, and the average age. In the result(s) column, “MP > FP” means it impacted more the male participants than the female participants. “FA > MA” means the female agent has more impact than the male agent. Explanations are in section 3.5.

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(Moreno et al., 2002)	<ul style="list-style-type: none"> • 2 MA • 2 FA • 3-D • Voice • Realist • Tutor 	<ul style="list-style-type: none"> • 12 MP • 27 FP • avg age 20 	Watching a video of a virtual agent giving a course, taking a multiple-choice test.	<ul style="list-style-type: none"> • Performance • Perceived masculinity, femininity 	<ul style="list-style-type: none"> • <i>Performance</i>: MA > FA • <i>Perceived masculinity, femininity</i>: <ul style="list-style-type: none"> - FA: very feminine - MA: masculine
(Baylor and Kim, 2004)	<ul style="list-style-type: none"> • 4 MA • 4 FA • 2-D, 3-D • Voice • Realist, cartoon • Tutor 	<ul style="list-style-type: none"> • 94 MP • 218 FP • avg age 20.54 	Creating an instructional schedule with a virtual agent's help.	<ul style="list-style-type: none"> • Self-efficacy • Self-regulation • Knowledgeability • Intelligence • Learning 	<ul style="list-style-type: none"> • <i>Self-efficacy, self-regulation, knowledgeability, intelligence</i>: MA > FA • <i>Learning</i>: not significant
(Baylor and Kim, 2004)	<ul style="list-style-type: none"> • 6 MA • 6 FA • 2-D, 3-D • Voice • Realist, cartoon • Expert, motivator, mentor 	<ul style="list-style-type: none"> • 89 MP • 140 FP • avg age 19.39 	Creating an instructional planning with a virtual agent's help.	<ul style="list-style-type: none"> • Knowledgeability • Intelligence • Learning • Self-regulation • Self-efficacy 	<ul style="list-style-type: none"> • <i>Knowledgeability, intelligence</i>: MA > FA • <i>Learning, self-regulation</i>: not significant • <i>Self-efficacy</i>: FA > MA

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(Moreno and Flowerday, 2006)	<ul style="list-style-type: none"> • 5 MA • 5 FA • 2-D • Voice • Realist • Tutor 	<ul style="list-style-type: none"> • 21 MP • 59 FP • avg age 26.88 	Watching a video of a course taught by a virtual agent, taking a test.	<ul style="list-style-type: none"> • Helpfulness • Motivation • Selected agent • Learning 	<ul style="list-style-type: none"> • <i>Helpfulness, motivation, learning</i>: not significant • <i>Selected agent</i>: matching-gender agent = opposite gender agent
(Kim et al., 2007)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 3-D • Voice • Realist • Companion 	<ul style="list-style-type: none"> • 11 MP • 45 FP • avg age 20.71 	Creating a course on economic concepts with a virtual agent's help.	<ul style="list-style-type: none"> • Facilitating learning • Engaging • Human-like • Learning (recall) 	<ul style="list-style-type: none"> • <i>Facilitating learning, engaging, human-like</i>: MA > FA • <i>Learning (recall)</i>: not significant
(Plant et al., 2009)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 3-D • Voice • Realist • Speaker 	<ul style="list-style-type: none"> • 45 MP • 61 FP • avg age 13.63 	Listening to a story about four female engineers and the benefits of engineering, either delivered by an agent or voice-only. Taking a math test.	<ul style="list-style-type: none"> • Interest • Utility • Self-efficacy • Performance • Fewer engineering gender stereotypes 	<ul style="list-style-type: none"> • <i>Interest, utility</i>: FA > MA & no agent • <i>Self-efficacy</i>: MA & FA > no agent • <i>Performance</i>: FA > MA • <i>Fewer engineering gender stereotypes</i>: <ul style="list-style-type: none"> - MP: agents > no agent - FP: FA & no agent > MA
(Hayes et al., 2010)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 3-D • Voice • Realist • Observer 	<ul style="list-style-type: none"> • 35 MP • avg age 19.77 	Controlling an avatar (1 st or 3 rd person view) while taking a math test, in the presence of a male or female agent, or without an agent.	<ul style="list-style-type: none"> • Social presence • Performance • Response times 	<ul style="list-style-type: none"> • <i>Social presence</i>: MA > FA & no agent • <i>Performance, response times</i>: <ul style="list-style-type: none"> - 1st person: no agent & MA > FA - 3rd person: FA > no agent & MA

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(Kim and Wei, 2011)	<ul style="list-style-type: none"> • 2 MA • 2 FA • 3-D • Voice • Realist • Tutor 	<ul style="list-style-type: none"> • 110 MP • 100 FP • avg age 15.93 	Taking a math test without an agent, watching an agent explaining the lessons, resolving math problems with the agent (training), taking a 2 nd math test without an agent.	<ul style="list-style-type: none"> • Selected agent • Performance 	<ul style="list-style-type: none"> • <i>Selected agent</i>: matching gender & matching ethnicity agents > others • <i>Performance</i>: everyone improved
(Silvervarg et al., 2013)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 1 neutral • 2-D • Text • Cartoon • Tutee 	<ul style="list-style-type: none"> • 46 MP • 37 FP • 12-14 years old 	Interacting with an androgynous virtual tutee on a math lesson, then with either a female or a male virtual tutee.	<ul style="list-style-type: none"> • Perceived androgyny • Preferred agent as tutee • Preferred agent as chat partner 	<ul style="list-style-type: none"> • <i>Perceived androgyny</i>: androgynous agent = androgynous • <i>Preferred agent as tutee</i>: <ul style="list-style-type: none"> - FP: androgynous agent > MA & FA - MP: androgynous agent > MA & FA (not significant) • <i>Preferred agent as chat partner</i>: <ul style="list-style-type: none"> - FP: androgynous agent > MA - MP: androgynous agent > FA
(Kim and Lim, 2013)	<ul style="list-style-type: none"> • 2 FA • 3-D • Voice • Realist • Tutor 	<ul style="list-style-type: none"> • 64 MP • 56 FP • avg age 15.93 	Taking a math test without an agent, learning lessons with or without an agent, resolving math problems with or without an agent (training), taking a 2 nd math test without an agent.	<ul style="list-style-type: none"> • Performance • Self-efficacy 	<ul style="list-style-type: none"> • <i>Performance</i>: everyone improved • <i>Self-efficacy</i>: <ul style="list-style-type: none"> - FP: agent present > no agent - MP: no increase

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(Kim, 2013)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 1 neutral • 2-D, 3-D • Voice, text • Cartoon • Tutor 	<ul style="list-style-type: none"> • 68 MP • 73 FP • avg age N/A 	Answering questions about a text asked by a virtual agent.	<ul style="list-style-type: none"> • Text comprehension 	<ul style="list-style-type: none"> • <i>Text comprehension:</i> - FP = MP - FP: MA & FA > robot agent - MP: MA > FA & robot agent
(Johnson et al., 2013)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 3-D • Voice • Cartoon • Tutor 	<ul style="list-style-type: none"> • 88 MP • 109 FP • avg age 12.1 	Watching an agent teaching a lesson on electrical circuits, taking a multiple-choice test.	<ul style="list-style-type: none"> • Performance • Program evaluation 	<ul style="list-style-type: none"> • <i>Performance:</i> not significant • <i>Program evaluation:</i> FA > MA
(Ozogul et al., 2013)	<ul style="list-style-type: none"> • 2 MA • 2 FA • 3-D • Voice • Cartoon • Tutor 	<ul style="list-style-type: none"> • 173 MP • 161 FP • avg age 12.3 	Watching an agent (chosen or randomly assigned) teaching a lesson on electrical circuits, taking a multiple-choice test.	<ul style="list-style-type: none"> • Performance • Program evaluation • Selected agent 	<ul style="list-style-type: none"> • <i>Performance:</i> - Random agent: not significant - Selected agent: opposite gender agent > matching-gender agent • <i>Program evaluation:</i> not significant • <i>Selected agent:</i> matching-gender agent > opposite gender agent
(Shiban et al., 2015)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 3-D • Text • Cartoon • Tutor 	<ul style="list-style-type: none"> • 21 MP • 73 FP • avg age 20.20 	Taking a math test while a virtual agent provided feedback.	<ul style="list-style-type: none"> • Interest • Motivation • Enjoyment • Credible • Engaging • Human-like • Facilitating learning • Performance 	<ul style="list-style-type: none"> • <i>Interest, motivation:</i> FA > MA • <i>Enjoyment:</i> not significant • <i>Credible, engaging, human-like:</i> MA > FA • <i>Facilitating learning:</i> not significant • <i>Performance:</i> MA > FA (slightly)

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(Kim, 2016)	<ul style="list-style-type: none"> • 2 MA • 2 FA • 3-D • Voice • Realist • Tutor 	<ul style="list-style-type: none"> • 67 FP • avg age 15.51 	Listening to an agent speak persuasively about the benefits of STEM fields, solving math problems with the same agent, solving math problems without the agent.	<ul style="list-style-type: none"> • Credibility • Friendliness • Helpfulness • Positive attitudes to learn math 	<ul style="list-style-type: none"> • <i>Credibility, friendliness, helpfulness:</i> <ul style="list-style-type: none"> - Ethnic-minority participants: <ul style="list-style-type: none"> - MA: peer agent > teacher agent - FA: teacher agent > peer agent - Caucasians participants: <ul style="list-style-type: none"> - MA & FA: not significant • <i>Positive attitudes to learn math:</i> <ul style="list-style-type: none"> - Ethnic-minority participants: <ul style="list-style-type: none"> - MA: peer agent > teacher agent - FA: teacher agent > peer agent - Caucasians participants: <ul style="list-style-type: none"> - MA & FA: not significant
(Krämer et al., 2016)	<ul style="list-style-type: none"> • 2 MA • 2 FA • 3-D • Voice • Realist • Motivating interviewer 	<ul style="list-style-type: none"> • 60 MP • 68 FP • avg age 23.85 	Taking a math test without an agent, then taking a math test with an agent present explaining the procedure.	<ul style="list-style-type: none"> • Motivation • Sense of rapport • Performance 	<ul style="list-style-type: none"> • <i>Motivation, sense of rapport:</i> not significant • <i>Performance:</i> <ul style="list-style-type: none"> - FP & rapport agent: MA > FA - MP & rapport agent: FA > MA
(Li et al., 2016)	<ul style="list-style-type: none"> • 1 MA • 1 neutral • 3-D • Voice • Realist • Tutor 	<ul style="list-style-type: none"> • 20 MP • 20 FP • avg age 20.48 	Watching an agent present slides on courses about Human-Computer Interaction.	<ul style="list-style-type: none"> • Learning 	<ul style="list-style-type: none"> • <i>Learning:</i> <ul style="list-style-type: none"> - MP: agent robot > real human (male) > MA > still image of a robot - FP: no differences
(Jeong et al., 2017)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 3-D • Voice • Realist • Instructor 	<ul style="list-style-type: none"> • 54 MP • 63 FP • avg age 20.94 	Listening to negative feedback from an instructor agent while acting out a scene. Reproducing the scene with the instructor agent and a student agent (no feedback).	<ul style="list-style-type: none"> • Moving forward • Moving backward 	<ul style="list-style-type: none"> • <i>Moving forward:</i> <ul style="list-style-type: none"> - FP: FA > MA - MP: MA > FA • <i>Moving backward:</i> <ul style="list-style-type: none"> - FP: MA > FA - MP: FA > MA

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(Pezzullo et al., 2017)	<ul style="list-style-type: none"> • 1 FA • 3-D • Voice • Realist • Companion 	<ul style="list-style-type: none"> • 54 MP • 63 FP • avg age 13.30 	Playing a game about biology courses with a virtual agent's help.	<ul style="list-style-type: none"> • Mental demand • Engagement with the agent • Performance 	<ul style="list-style-type: none"> • <i>Mental demand, engagement with the agent: FP > MP</i> • <i>Performance: FP = MP</i>
(Wirzberger et al., 2019)	<ul style="list-style-type: none"> • 1 MA • 3-D • Voice • Realist • Instructor 	<ul style="list-style-type: none"> • 27 MP • 35 FP • avg age 69.03 	Memorizing a word list after taking a memory training course led by an agent.	<ul style="list-style-type: none"> • Learning (recall) 	<ul style="list-style-type: none"> • <i>Learning (recall): FP > MP</i>
(Makransky et al., 2019)	<ul style="list-style-type: none"> • 1 FA • 1 neutral • 3-D • Voice • Realist • Tutor 	<ul style="list-style-type: none"> • 33 MP • 33 FP • avg age N/A 	Watching a virtual agent teaching laboratory safety, taking tests.	<ul style="list-style-type: none"> • Social presence • Learning (recall and transfer-learning) 	<ul style="list-style-type: none"> • <i>Social presence:</i> - FP: FA = drone agent - MP: FA > drone agent • <i>Learning (recall & transfer-learning):</i> - FP = MP - FP: FA > drone agent - MP: drone agent > FA
(Chang et al., 2019)	<ul style="list-style-type: none"> • 1 MA • 3-D • Voice • Realist • Instructor 	<ul style="list-style-type: none"> • 76 FP • avg age N/A 	Controlling either a male or a female avatar, learning how to solve arithmetic problems from a male agent (either a dominant or a non-dominant agent, based on his body posture), solving problems without the agent present.	<ul style="list-style-type: none"> • Learning (recall & performance) 	<ul style="list-style-type: none"> • <i>Learning (recall & performance):</i> - non-dominant agent > dominant agent - No significant effect of avatar's gender

Author(s)	Agent(s)	Participant(s)	Task(s)	Measure(s)	Result(s)
(Sajjadi et al., 2020)	<ul style="list-style-type: none"> • 1 MA • 1 FA • 3-D • Voice • Realist • Instructor 	<ul style="list-style-type: none"> • 8 MP • 4 FP • avg age 19.6 	Observing geologic formations in a virtual environment, answering questions asked by an agent.	<ul style="list-style-type: none"> • Perceived learning effectiveness • Learning • Leadership • Friendliness • Social and spacial presence 	<ul style="list-style-type: none"> • <i>Perceived learning effectiveness</i>: FA > MA • <i>Learning</i>: not significant • <i>Leadership, friendliness, social and spacial presence</i>: FA > MA (not significant)
(Spiliotopoulos et al., 2020)	<ul style="list-style-type: none"> • 1 FA • 3-D • Voice • Realist • Tutor 	<ul style="list-style-type: none"> • 24 MP • 16 FP • avg age 20 	Learning how to use argumentation, how to be empathetic to the needs of others, how to reach agreements through negotiation with a virtual agent.	<ul style="list-style-type: none"> • Self-efficacy • System easiness • Helpfulness • Learning 	<ul style="list-style-type: none"> • <i>Self-efficacy</i>: not significant • <i>System easiness</i>: FP > MP • <i>Helpfulness</i>: MP > FP • <i>Learning</i>: not significant (increase overall)

288 Various studies on virtual learning environments (Table 2) have reported that the gender of a pedagogical
289 agent may have an impact on the learning performance of users. In a recent article, Makransky et al.
290 (2019) showed that young girls performed better on scientific tasks (in terms of learning and transfer
291 learning) when taught by a virtual female scientist than by a virtual drone. The opposite was true for
292 boys. The researchers argued that boys identified with the drone, while girls identified with the female
293 agent. However, research opposing human-like vs. robot-like agents does not take into account other
294 factors that may influence how girls learn. In a study by Shiban et al. (2015), female learners were more
295 motivated and interested in math when trained by a female agent as compared to a male agent. However,
296 they obtained better results with the male agent, which may be explained by their perception of the agents'
297 appearances: the male agent was older and wore a tie, while the female agent was young and pretty.
298 According to the authors, the participants' performance improved because the male agent was perceived
299 as an expert, and virtual agents perceived as experts have been shown to improve learners' performance
300 (Baylor and Kim, 2004). The researchers also concluded that the female participants' motivation and
301 interest improved with the female agent because there were more female participants in the study and
302 because of the agent's similarity (in age and gender) to them, in line with the "similarity hypothesis" (also
303 found in Rosenberg-Kima et al. (2008)). This argument is supported by Bandura's social cognitive learning
304 theory: people often learn by imitating people whom they perceive as similar (or superior: higher in rank
305 or status) to them and who are therefore accepted as social role models (Bandura, 1986). This theory
306 also bears out in a study by Plant et al. (2009), where a female agent raised participants' self-efficacy by
307 delivering a message on the benefits of engineering, resulting in better performance and more interest in
308 math.

309 However, other research has demonstrated a positive effect of male agents as compared to female agents
310 in pedagogical tasks. For instance, in two experiments conducted by Baylor and Kim (2004), a virtual agent
311 helped participants create a schedule. The agent's gender did not impact learning but did affect self-efficacy,
312 which increased more in the first experiment with the male agent than the female agent; the contrary
313 occurred in the second experiment for both male and female participants. The researchers suggested that
314 there was a bias in the first experiment, as participants rated the male agent as more interesting and useful
315 than the female agent. In the second experiment, participants viewed the female agent as less expert
316 and knowledgeable than the male agent, despite receiving the same instructions from both agents; some
317 research has indicated that agents perceived as less intelligent could lead to greater self-efficacy Baylor
318 and Kim (2005). In a similar experiment by Kim et al. (2007), the researchers introduced a female and a
319 male pedagogical agent to help students design an e-learning course, which included creating a schedule.
320 Students working with the male agent rated him higher on facilitating learning, being engaging, and being
321 human-like than students working with the female agent. Notably, the male agent had a more positive
322 impact than the female agent on the participants' interest and learning in terms of recall (the ability to
323 remember what the agent said during the task).

324 Other factors may also be come into play in studies on the impact of virtual agents on learning. In
325 Moreno et al. (2002), participants watched a video of a virtual agent presenting a course on blood pressure,
326 followed by a multiple-choice test. The results of this study suggest that the participants learned more
327 from the male agent than the female one. The researchers suggested that this might be because the female
328 tutor did not conform to the stereotype of men as teachers. The first study showed that participants in
329 this experiment perceived the female agent as very feminine, while the male agent was found to be very
330 masculine. This may be due to a difference in the participants' interpretation of the female agent as being
331 "too feminine" to be suitable for the role of tutor. The study did not address how participants perceived the
332 agents' expertise or seek to determine any possible interactions between perceived expertise, the perceived

333 agent's femininity and performance on the test. Gender, while important, must be taken into account in
334 combination with other features. For instance, Krämer et al. (2016) analyzed the impact of pedagogical
335 agents' gender and their behavior on adults' motivation, effort and performance in math. They found that
336 the simple presence of a female virtual agent in a learning situation did not increase women's motivation
337 and learning. However, when the agent displayed human-like non-verbal behavior by aligning with the
338 participants' non-verbal behavior (Gratch et al., 2007), the participants' performance and effort improved.
339 This kind of behavior, called rapport, is defined in social psychology as the establishment of a positive
340 relationship between interactants by way of a positive attitude (e.g., acquiescence, smiles), mutual attention
341 (e.g., mutual gaze) and coordination of behaviors (e.g., synchrony, mimicry) (Tickle-Degnen and Rosenthal,
342 1990). This research shows the importance of the pedagogical agents' behavior combined with their gender
343 as providing a positive impact on academic outcomes. Agents' behavior is especially important as it could
344 negatively impact learners' academic outcomes, as shown in an experiment by Chang et al. (2019) where a
345 male "dominant" pedagogical agent impaired female participants' performance and recall in arithmetic
346 problems, compared to a male "non-dominant" agent.

347 The research presented above highlights the importance of pedagogical agents' gender on learning.
348 Different studies appear to yield contradictory results, on one hand that learning improves when virtual
349 agents' gender matches the learner's, but on the other hand that male virtual agents could be better suited to
350 improving learning. Interestingly, Section 3.4 shows that male agents are perceived as more competent than
351 female agents, and users follow more advice from a male agent than a female one in topics stereotypically
352 perceived as masculine. However, the studies featuring a female agent in STEM fields (Science, Technology,
353 Engineering, and Mathematics) presented in this section show that female agents have a positive influence
354 on academic outcomes: they improve learning, self-efficacy, interest, and motivation, despite the fact that
355 STEMs are perceived as masculine (Makarova et al., 2019).

4 DISCUSSION

356 4.1 The question of pedagogical agents' gender.

357 Based on the research presented above, one could surmise that, in general, male pedagogical agents are
358 better suited to improving academic outcomes than female agents. However, systematically relying on
359 male pedagogical agents could have an adverse impact: designing only male agents for learning purposes
360 in STEM fields could strengthen gender stereotypes, for instance. As highlighted by West et al. (2019), the
361 gender bias of interactive systems not only perpetuates stereotypes, but also reinforces and extends them.
362 The stereotypes modeled through interactive systems generate behaviors that go beyond the sphere of the
363 virtual environment by conveying a harmful image of women. For instance, in a study by Dill et al. (2008),
364 still pictures of men and women in suits or male and female characters acting in highly stereotypical ways
365 were shown to participants. Male participants exposed to negative female stereotypes were significantly
366 more tolerant of a real-life instance of sexual harassment and exhibited greater rape myth acceptance. As
367 for representation in STEM fields, as noted by Sansone (2019), the lack of female role models can lead
368 female students to believe that men are better than women in STEM fields. The lack of *virtual* female role
369 models in virtual learning environments may have the same impact. Accordingly, more STEM experts
370 represented with virtual female characters could help decrease gender stereotypes in STEM fields.

371 Some research has explored the use of androgynous virtual agents to counter gender stereotypes. In
372 earlier studies, participants tended to apply the labels of 'man' or 'woman' to androgynous agents. For
373 instance, in Niculescu et al. (2009), participants classified androgynous virtual characters as male or female,

374 depending on the participants' gender and other parameters such as which virtual characters they had
375 seen before. Even for genderless agents such as a wooden mannequin, the participants perceived their
376 gender depending on how they perceived their walking motions (McDonnell et al., 2009). Recent research
377 has shown more promising results in terms of gender stereotypes. In Nag and Yalçın (2020), results for
378 androgynous agents show a linear trend that positions their scores for perceived agency, communion, and
379 competence in between those for female and male agents. The authors thus believe that androgynous agents
380 could help mitigate male and female stereotypes. Although participants in their first experiment tended to
381 believe that the androgynous virtual agents were men, when the authors modified the agents in question for
382 their main experiment, participants correctly perceived them as androgynous after reading a definition of
383 an androgynous agent.

384 What about androgynous pedagogical agents in an educational context? Silvervarg et al. (2013) supposed,
385 but with caution, that students could identify with an androgynous agent by ascribing their own gender
386 on them, thus making them a suitable role model. Indeed, in their experiment with children aged 12-14,
387 participants perceived an androgynous pedagogical agent as not clearly a boy nor clearly a girl, but they
388 generally assigned themselves a gender to their androgynous virtual tutee, boy or girl. The authors supposed
389 students could therefore have more freedom to construct and ascribe gender, as their pedagogical agent's
390 gender choice is personal rather than imposed. They also supposed androgynous agents could diminish
391 gender stereotypes, as their appearances are genderless. Applying our own gender to an androgynous agent
392 to make them a suitable role model is an interesting hypothesis, however, we do not know what is the
393 gender participants applied on the androgynous agent, nor why. More research on androgynous agents
394 has to be done in an educational context to help determine, for instance, whether androgynous agents are
395 perceived as masculine, feminine, neutral, man, woman, or genderless depending on the context and the
396 role of the agent. Since STEM fields are considered masculine fields (Makarova et al., 2019), participants
397 could perceive an androgynous agent as a man, even though they could perceive them as not clearly a boy
398 nor a girl in term of appearance. This could reinforce the stereotype of STEM fields as more suitable for
399 men than women. Agents' role is also particularly important, as Brahnam and Weaver (2015) stated there
400 are more female assistant agents than male one. They showed the example of a webpage that provides
401 virtual agents, four of the five virtual agents are female and they assist people at airports or serve as talking
402 mannequins for fashion and museum exhibits. The male agent was called a "virtual doctor" and provided
403 health tips and hospital information. We can emit the hypothesis that one could perceive androgynous
404 virtual assistants as women, hence reinforcing gender stereotypes. For this research on androgynous virtual
405 agents, we recommend measuring how participants feel towards the androgynous agents, as not being able
406 to perceive someone as a man or a woman may induce insecurity and unease in some people (Nass and
407 Brave, 2005).

408 **4.2 Virtual agents as social role models in learning environments**

409 Some research, though still very limited, has explored the use of virtual agents to increase learners'
410 performance and interest in mathematics. For example, Rosenberg-Kima et al. (2008) showed the
411 effectiveness of a female virtual agent engineer in interesting women in STEM fields. In a video, the agent,
412 who was similar in gender to the participants (who were all women), presented a story about successful
413 female role models in STEM fields. This led to a change in participants' attitudes towards science, as
414 shown with a 7-point scale questionnaire. Women in the female virtual agent condition were less likely to
415 endorse traditional STEM stereotypes than those in the male virtual agent condition, and were more likely
416 to believe that women could succeed in STEM fields. Gender stereotypes still persisted: the participants
417 were slightly more likely to believe in STEM usefulness with a male virtual agent engineer. In a similar

418 study by Plant et al. (2009), male and female participants performed better and were more interested in
419 engineering after interacting with a female agent: she raised their self-efficacy and their ratings about
420 STEM usefulness. Interestingly, male participants were less likely to endorse traditional STEM stereotypes
421 in the presence of an agent, male or female; but female participants were less likely to endorse traditional
422 STEM stereotypes with a female agent or without any agent, than with a male one. Another similar study
423 by Rosenberg-Kima et al. (2010) showed that Black virtual agents had a more positive impact on STEM
424 interest and STEM gender stereotypes for Black women, whereas female virtual agents (Black or White)
425 had a more positive impact on White women on the same criteria. This research shows the importance of
426 other factors, such as virtual agents' ethnic background, on performance and interest in math.

427 Finally, several studies have shown that pedagogical agents used as learning companions can simulate
428 social interactions (Kim and Baylor, 2006) and the potential impact of a virtual agent's gender on education.
429 However, only a few studies have explored the use of a virtual pedagogical companion to counteract
430 the effects of Stereotype Threat (see Introduction). Research on Social Cognition has shown the positive
431 impact of social role models to counteract ST effects (Bagès et al., 2016). Studies have shown that female
432 participants do not immediately see female scientists as potential role models simply by interacting with
433 them; they begin to perceive female scientists as role models when they establish personal connections
434 with them (Buck et al., 2008). In the field of virtual agents, virtual rapport has been studied as a means
435 to create this type of relationship between virtual agents and users (Gratch et al., 2007). As reported by
436 Krämer et al. (2016), the mere presence of a female agent did not improve participants' performance and
437 effort. However, when agents were able to create a virtual rapport, participants' performance and effort
438 were shown to improve.

439 Based on the research presented above, not only is the gender of pedagogical agents important, but so is
440 their behavior (Krämer et al., 2016; Chang et al., 2019), their role (Baylor and Kim, 2004; Kim, 2016), and
441 their ethnicity (Rosenberg-Kima et al., 2010; Kim, 2016). Girls may see a female pedagogical agent as a
442 role model who influences their motivation to exert effort to learn (Shiban et al., 2015). A study by Pfeifer
443 and Lugin (2018) shows that female social robots can be role models to female students: female students
444 learned better with a female robot in a stereotypically masculine domain. Virtual characters can be used
445 to embody social models and thus change the learner's attitudes and motivation; as described earlier, a
446 female role model who succeeds in math can reduce Stereotype Threat effects. Combining research on
447 social cognition and on virtual agents, we recommend counteracting Stereotype Threat effects for girls
448 and women in math by using a virtual agent representing a hardworking female social role model (Bagès
449 et al., 2016) able to establish rapport with the learners (Gratch et al., 2007), of a similar ethnicity to the
450 learners (Kim, 2016) and slightly older than them (Bagès and Martinot, 2011). When the role model is
451 younger or the same age as the learners, they can lose motivation by feeling unable match their role model's
452 achievements; if the model is too old, they won't identify with her/him. A pedagogical agent should thus
453 embody the role of a knowledgeable and motivational person; this has been demonstrated by student
454 preferences and by the proven positive impact these types of agents have on education (Kim and Baylor,
455 2016).

456 **4.3 Improved learning or better inclusion?**

457 An ethical tension between two competing goals arises in all domains: skill learning (where the research
458 presented above favors the use of a male virtual agent), vs. better inclusion of girls and women (via the use
459 of a female virtual character embodying a successful role model in the domain). Prior research is not robust
460 enough to prove the superiority of a male agent in all fields and for all audiences. Some questions remain

461 unanswered in the literature, to our knowledge: Would using the same androgynous character but presented
462 as male, female, or neutral by the experimenter have an impact on academic outcomes in scientific or other
463 domains? What would be the impact of systematically using a virtual agent of the same gender as the
464 learners?

465 Regarding the second question, using only successful male models in mathematics with boys could
466 reinforce gender stereotypes. Women are aware of the negative stereotype about their mathematical skills
467 that create a hostile environment for them. Research by Stokes et al. (1995) reported that when women find
468 a friendly environment, they are more likely to stay employed. One solution to reconciling the two goals,
469 at least in STEM fields, would be to use successful female role models to explain how they managed to
470 perform well: in Bagès et al. (2016), students took a math test after reading a story about a social model,
471 female or male depending on the condition. The stories differentiated between models: the hardworking
472 model put in effort and spent time learning his or her lessons to perform well, the gifted model was naturally
473 good at math, and the neutral model gave no explanation for his or her success. Girls' performance increased
474 with the hardworking model: they performed at the same level as boys, whether the model was a boy or a
475 girl. There was no impact on boys' performance. In contrast, in a similar study, boys' performance also
476 increased with a hardworking model, regardless of gender (Bagès and Martinot, 2011). Furthermore, when
477 the role model did not explain his or her success in math, both girls' and boys' scores improved with a
478 female role model. As the lack of female role models may lead female students to believe that men are
479 better than women in STEM fields Sansone (2019), it could be interesting to combine the results of (Bagès
480 et al., 2016) and our hypothesis that a successful *virtual* female role model in STEM fields could help
481 mitigate gender stereotypes. Female virtual agents who act as successful social models in mathematics and
482 explain how they succeeded through their effort and hard work may be a potential solution to counteracting
483 Stereotype Threat effects. Another question then arises: in the long term, what would be the impact of
484 presenting only these kinds of female virtual agents to boys?

5 CONCLUSION

485 In this article we have presented a systematic review of research on perceptive studies of virtual agents
486 depending on their gender, regardless of the application domain; and on the impact of gendered virtual
487 agents in the context of a learning task. Each study has been performed in a specific learning context with
488 specific pedagogy, design of the virtual environment, duration of the interaction, modality of interaction,
489 physical environment, etc. These elements of context may have an impact on the users' perceptions and
490 learning outcomes. One limit of this article is that we have not considered all these contextual specificities.
491 Further analysis could take into account these contextual elements to provide a more global view of the
492 impact of virtual agents' gender in academic learning. Nevertheless, the present systematic review enables
493 us to draw some conclusions by answering each question stated in Section 2.2.

494 *Do students perceive virtual agents differently depending on their own gender and the gender of the*
495 *agent?* As individuals communicate with virtual agents by applying social rules and expectations as social
496 beings (Nass and Moon, 2000), it is not surprising that they also apply gender stereotypes to virtual agents
497 and their interactions with them (see Section 3.4). Female virtual agents are usually seen as less expert, less
498 knowledgeable, and less powerful than male virtual agents (Nunamaker et al., 2011; Baylor and Kim, 2004),
499 and they are also usually perceived as more likable and attractive than male virtual agents (Nunamaker
500 et al., 2011; Lunardo et al., 2016). Those perception differences can even affect people's decisions (Lee,
501 2003; Świdrak et al., 2021).

502 Given the empirical results, we propose to respond simultaneously to question 2 (*Does the gender of*
503 *pedagogical agents influence students' academic performance and self-evaluations?*) and question 3 (*Are*
504 *there tasks or academic situations which a male virtual agent is better suited to than a female virtual*
505 *agent, and vice versa, according to empirical evidence?*). The review conducted in this paper could lead to
506 believe that male pedagogical agents are better suited than female agents to improve academic outcomes,
507 especially in male-dominated scientific fields like STEM fields (Makarova et al., 2019). However, research
508 also shows that female pedagogical agents can improve learners' performances in these fields (Plant et al.,
509 2009; Rosenberg-Kima et al., 2008). Some studies have shown that using female virtual agents as social
510 role models can increase female participants' self-efficacy (Rosenberg-Kima et al., 2008), and both male
511 and female participants' interest (Plant et al., 2009; Rosenberg-Kima et al., 2010), and performances (Plant
512 et al., 2009). These results are especially relevant to address Stereotype Threat effects, a phenomenon
513 that illustrates how and why female students' performance in math can be impaired by gender stereotypes
514 (Spencer et al., 1999). Previous research showed that stereotype threat effects can be counteracted by
515 introducing a female positive role model who looks like learners so that they can identify with (Bagès et al.,
516 2016). Such a positive role model could be embodied by a virtual pedagogical agent (Rosenberg-Kima
517 et al., 2008), and used to reduce stereotype threat in STEM fields.

518 *How do a virtual agent's pedagogical roles impact these results?* Individuals tend to listen more to
519 agents whose gender stereotypically matches the context or gender roles such as female virtual agents with
520 cosmetics and male virtual agents with sports (Lee, 2003), female virtual agents in contexts involving social
521 influence (Khashe et al., 2017), and female virtual agents in an assistant role (Esposito et al., 2021)). The
522 role of virtual pedagogical agent has been studied in academic context, using *expert*, *motivator*, and *mentor*
523 agents (Baylor and Kim, 2004). Expert agents are older than students, authoritative, strictly informative,
524 and knowledgeable. Motivator agents are enthusiastic and not seen as particularly knowledgeable, they
525 are mostly used to elicit motivation. As for mentor agents, they are slightly older than students, are
526 knowledgeable, and they are also used to elicit motivation. They are a mix of expert agents and motivator
527 agents (Baylor and Kim, 2005). Researchers should take agents' role into account when designing a
528 pedagogical agent, as a female pedagogical agent designing as a mentor agent can improve learners'
529 performance (Plant et al., 2009), but a female pedagogical agent designing as a motivator agent may not be
530 effective on learners' performance (Shiban et al., 2015). In conclusion, the impact of the virtual agent's
531 gender depends on several aspects related to the role of the agent. This role is indeed reflected through for
532 instance the appearance but also the discourse of the agent.

533 *How do a virtual agent's appearance and interactive capacities impact these results?* The topics of
534 individuals' interactions with virtual agents differ depending on their gendered appearance: in studies
535 by De Angeli and Brahnem (2006) and Brahnem and De Angeli (2012), female virtual agents received
536 significantly more violent sexual propositions, more rape threats, more comments on their appearance, and
537 more swear words compared to male virtual agents who received few sexual propositions, most of them
538 targeting their girlfriends. Moreover, the degree of perceived masculinity and femininity can influence
539 men's decision, as shown in Świdrak et al. (2021) where male participants were persuaded more by
540 masculine agents than feminine agents, regardless of the agents' gender. Agents' appearance can influence
541 their perceived role, as an old agent wearing a tie could be perceived more as an expert than a young
542 agent (Shiban et al., 2015). As seen in the question above, agents' role is important in academic situations.
543 In addition to agents' role and appearance, research has shown the importance of a positive relationship
544 between learners and pedagogical agents (Krämer et al., 2016). This research tends to show that a female
545 social model embodied by a pedagogical agent able to establish a positive relationship with learners may

546 counteract Stereotype Threat effects, and thus improve women's performance, interest, and self-efficacy in
547 mathematics.

548 *Are androgynous virtual agents a potential solution to combatting gender stereotypes?* This question is
549 quite difficult to answer as to our knowledge, few research has explored the use of androgynous virtual
550 agents to counter gender stereotypes in academic context. Silvervarg et al. (2013) used an androgynous
551 pedagogical agent in an educational context and showed participants, although evaluating the agent as
552 "not clearly a boy nor a girl", tend to ascribe a binary gender (boy or girl) on the agent. The authors thus
553 cautiously supposed that students could ascribe their own gender on an androgynous agent, thus giving
554 them more freedom and making the agent a suitable role model, known to be beneficial for academic
555 outcomes. However, results did not show what gender participants ascribe on the agent, nor why. The way
556 individuals ascribe gender to an androgynous or a genderless agent should be studied more. In particular,
557 does this gender attribution depend on the context or agents' role? Since STEM fields are considered
558 masculine fields (Makarova et al., 2019), participants could think androgynous agents are men. This could
559 reinforce the stereotype of STEM fields as more suitable for men than women. As for agents' roles, there
560 are more female virtual assistants than male ones (Brahnam and Weaver, 2015). Some developers admitted
561 female virtual assistants are usually used because they evoke gender stereotypes: women are expected
562 to serve, help, and nurture others. Androgynous virtual assistants could then be considered women, and
563 reinforce harmful stereotypes on women. Researchers and developers who want to use androgynous agents
564 to combatting gender stereotypes should be very careful, as the opposite effect can occur.

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