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Systematic Review of Adaptive Learning Research Designs, Context, Strategies, and Technologies From 2009 to 2018

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1 Systematic review of adaptive learning research designs, 2 context, strategies, and technologies from 2009 to 2018

3 Florence Martin¹ · Yan Chen² · Robert L. Moore³ · Carl D. Westine¹ 

4
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6 Abstract

7 This systematic review of research on adaptive learning used a strategic search process to
8 synthesize research on adaptive learning based on publication trends, instructional con-
9 text, research methodology components, research focus, adaptive strategies, and technolo-
10 gies. A total of 61 articles on adaptive learning were analyzed to describe the current state
11 of research and identify gaps in the literature. Descriptive characteristics were recorded, **AQ1**
12 including publication patterns, instructional context, and research methodology compo-
13 nents. The count of adaptive learning articles published fluctuated across the decade and
14 peaked in 2015. During this time, the largest concentration of adaptive learning articles
15 appeared in *Computers and Education*. The majority of the studies occurred in higher edu-
16 cation in Taiwan and the United States, with the highest concentration in the computer **AQ2**
17 science discipline. The research focus, adaptive strategies, and adaptive technologies used
18 in these studies were also reviewed. The research was aligned with various instructional
19 design phases, with more studies examining design and development, and implementa-
20 tion and evaluation. For examining adaptive strategies, the authors examined both adaptive
21 sources based on learner model and adaptive targets based on content and instructional
22 model. Learning style was the most observed learner characteristic, while adaptive feed-
23 back and adaptive navigation were the most investigated adaptive targets. This study has
24 implications for adaptive learning designers and future researchers regarding the gaps in
25 adaptive learning research. Future studies might focus on the increasing availability and
26 capacities of adaptive learning as a learning technology to assist individual learning and
27 personalized growth.

28 **Keywords** Adaptive learning · Adaptive strategy · Adaptive technology · Adaptive target ·
29 Adaptive source

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30 Introduction

31 Adaptive learning is considered an emerging educational, technological innovation in
32 higher education (New Media Consortium [NMC] 2018). It has pedagogical benefits,
33 including acceleration, remediation, metacognition, mastery-based learning, immedi-
34 ate feedback, and interactive learning (Hattie 2008). Researchers have described adaptive
35 learning both as a technology and a process. Kerr (2016) described adaptive learning as an
36 educational technology that aims to generate “automated, dynamic, and interactive” con-
37 tent (p. 88). Lowendahl et al. (2016) defined adaptive learning as a process that “dynam-
38 ically adjusts the way that instructional content is presented to students based on their
39 comprehension of the material as revealed in their responses to embedded assessments or
40 learner preferences such as visual presentation of materials” (p. 7). Whether considered **AQ3**
41 a technology or a process, adaptive learning results in a unique learning experience by
42 accounting for individual differences (•Liu et al. 2017a) to improve the scholastic path,
43 learning process, and learner satisfaction in varied learning situations (Rosita et al. 2016).
44 Adaptive learning can be implemented by developing adaptive web applications and sys-
45 tems to provide adaptability and intelligence assistance (•Dziuban et al. 2016; •Tosheva
46 and Martinovska 2012), employing adaptive learning design framework, instructions, and
47 adaptive teaching styles (•Bower 2016; •Tseng et al. 2008; Yang et al. 2013b), and apply-
48 ing adaptive learning sequences (•Wang and Liao 2011).

49 Previous adaptive learning reviews

50 From our review, there have been six systematic reviews conducted on adaptive learning
51 (See Table 1). Previous literature reviews of adaptive learning studies addressed the sig-
52 nificance of the adaptivity of the employed e-learning system as well as the adaptability for
53 learners to take control of the system. As such, the focus of these reviews has centered on
54 the adaptive criteria, distinct features within an adaptive learning system such as individual
55 differences, personal traits such as learning styles, and the effectiveness of adaptive learn-
56 ing (Akbulut and Cardak 2012; Kumar et al. 2017; Normadhi et al. 2019; Truong 2016;
57 Verdú et al. 2008).

58 While Verdú et al. (2008) examined the effectiveness of adaptive learning systems
59 in their review, the remaining studies mainly focused on specific learner characteris-
60 tics including personal traits, individual differences, and learning styles (Akbulut and
61 Cardak 2012; Kumar et al. 2017; Nakic et al. 2015; Normadhi et al. 2019). By includ-
62 ing the content and instructional models along with the learner model in their review of
63 learner characteristics, •Vandewaetere et al. (2011) expanded the focus beyond adaptiv-
64 ity in the learner model. The learner model refers to learner characteristics, whereas the
65 content model refers to knowledge domain characteristics and the instructional model
66 refers to the pedagogical aspects. •Vandewaetere et al. (2011) demonstrate the impor-
67 tance of expanding the review of the literature to include the adaptive target and the
68 pathway to the goal, as the learner model only constitutes one intermediate input to
69 the generation of productive adaptive environments. The learner and content model is
70 referred to as the adaptive target, and the adaptive path to reach this is referred to as the
71 pathway to the goal. The limited attention beyond the source in review studies from the
72 past decade, which generally focus only on understanding what will be adapted, consti-
73 tutes an essential opportunity for continued investigation. Instructional designers must

Table 1 Review studies on adaptive learning research

	Authors	Year published	Article	Years research reviewed	Number of studies reviewed	Adaptive focus
1	Normadhi, Shuib, Nasir, Bimba, & Balakrishnan	2019	Identification of personal traits in adaptive learning environment: Systematic literature review, <i>Computers & Education</i> , 130, 168–190	2010–2017	78	Personal traits
2	Kumar, Singh & Ahuja	2017	Learning styles based adaptive intelligent tutoring systems: Document analysis of articles published between 2001. and 2016. <i>International Journal of Cognitive Research in Science, Engineering, and Education</i> , 5(2)	2001–2016	78	Learning styles
3	Nakic, Granic, & Glavinic	2015	Anatomy of student models in adaptive learning systems: A systematic literature review of individual differences from 2001 to 2013. <i>Journal of Educational Computing Research</i> , 51(4), 459–489	2001–2013	98	Individual differences
4	Akbulut, & Cardak	2012	Adaptive educational hypermedia accommodating learning styles: A content analysis of publications from 2000 to 2011. <i>Computers & Education</i> , 58(2), 835–842	2000–2011	70	Learning styles
5	Vandewaetere., Desmet, & Clarebout	2011	The contribution of learner characteristics in the development of computer-based adaptive learning environments. <i>Computers in Human Behavior</i> , 27(1), 118–130	1993–2009	52	Learning characteristics

Table 1 (continued)

	Authors	Year published	Article	Years research reviewed	Number of studies reviewed	Adaptive focus
6	Verdú, Regueras, Verdú, De Castro, & Pérez	2008	Is adaptive learning effective? A review of the research. In WSEAS International Conference. Proceedings. Mathematics and Computers in Science and Engineering (No. 7). World Scientific and Engineering Academy and Society	1997–2007	15	Effectiveness of adaptive learning systems

74 consider all perspectives in developing and refining adaptive interventions, so there is a
75 clear need to review research that extends beyond the learner model.

76 Drawing on previous reviews of adaptive learning, we place our emphasis more
77 broadly on content and instructional models along with learner models. We also review
78 adaptive learning technology through a systematic review covering a 10-year timeframe
79 from 2009 to 2018. This timeframe strategically extends beyond the work of •Vande-
80 waetere et al. (2011) to highlight more recent advances in the integration of adaptive
81 learning strategies involving instruction to provide a more complete picture of research
82 within the adaptive learning framework, which collectively depends upon learners, con-
83 tent, and instruction.

84 Adaptive learning framework

85 We designed our adaptive learning framework (see Fig. 1) to include elements from
86 both Shute and Towle (2003) and •Vandewaetere et al. (2011). Shute and Towle (2003)
87 describe an adaptive learning framework that includes a learner model, a content model,
88 a tutoring model, and the adaptive engine. However, they do not refer to an adaptive
89 source and target or the outcome of the model. In their framework, •Vandewaetere et al.
90 (2011) model the source and target, but the three models (i.e., learner, instructional, and
91 content) were not depicted. They included interaction in the source and both presenta-
92 tion and support in the target, but did not include an outcome.

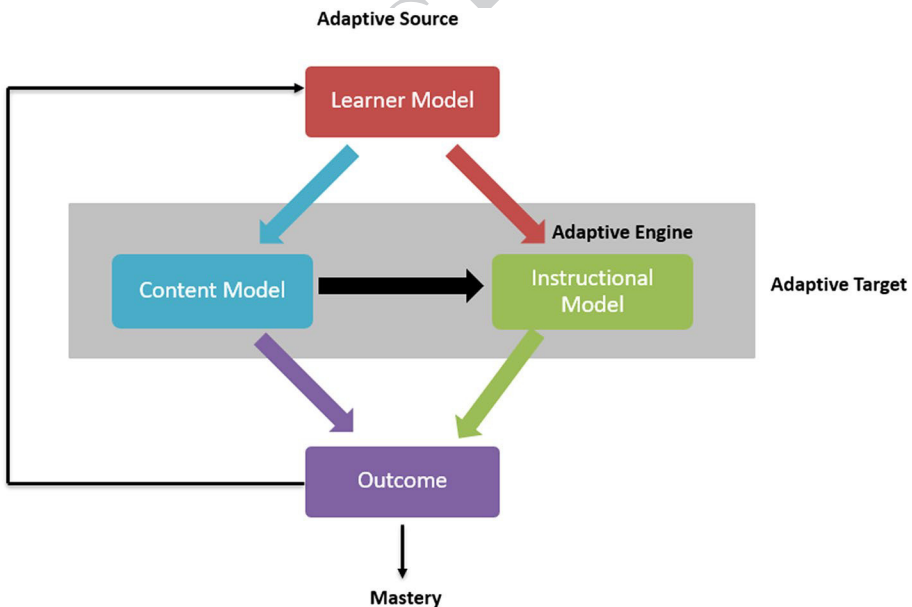


Fig. 1 Adaptive learning models framework adapted from Shute and Towle (2003) and •Vandewaetere et al. (2011)

93 Learner model

94 *Learner Model*, also known as the student model, refers to the learner characteristics
95 of what a student knows and does (•Vandewaetere et al. 2011). The Learner Model
96 includes learner attributes, learner preferences, learner knowledge and proficiency,
97 motivational or emotional aspects of learner behavior, and individual differences that
98 are used to adapt the learning (Martin and Markant 2019). This model could include
99 affective, behavioral, and cognitive characteristics of the learner. •Vandewaetere et al.
100 (2011) refer to the learner model as an adaptive source.

101 Content model

102 *Content Model*, also known as the expert or domain model, refers to the content or
103 knowledge base for the course (•Vandewaetere et al. 2011). This Content Model could
104 involve concepts that build on each other and includes a learning map with relationships
105 between different ideas and how the course content is delivered to the learner (Martin
106 and Markant 2019).

107 Instructional model

108 *Instructional Model*, also known as the pedagogical model, refers to the algorithm that
109 assists in adapting the instruction based on the content and learner model. The Instruc-
110 tional Model is also referred to as the adaptation model as it defines what, when, and
111 how adaptation can occur (Paramythis and Loidl-Reisinger 2004). Some of the adapta-
112 tion techniques include pacing, the format of instruction, and sequencing (Martin and
113 Markant 2019). This model provides the base for deciding what content is presented
114 to the learner and can also be called the adaptation model since it describes what is
115 adapted and how it is adapted (•Vandewaetere et al. 2011).

116 Adaptive source and adaptive target

117 The learner model is referred to as the adaptive source. The content model and the
118 instructional model are together called the adaptive target (•Vandewaetere et al. 2011).
119 While the adaptive source refers to the characteristics (“to what will it be adapted”), the
120 adaptive target refers to the content and instruction that will be adapted (“what will be
121 adapted”) (•Vandewaetere et al. 2011, p. 122).

122 Adaptive engine

123 The Adaptive Engine can be described as an artificial intelligence (AI) sequence genera-
124 tor where a learning map with instructional content will be created for the learner in the
125 instructional model. Shute and Towle (2003) describe the adaptive engine as involved
126 in selecting the topic, identifying objectives, sequencing them, and presenting them
127 to meet the learner’s needs until the learner achieves mastery. The intelligent engine
128 assists the learner by introducing content that incrementally augments their knowledge
129 by identifying content that builds on what they already know (Lynch and Howlin 2014).
130 AI techniques combine models of content, instruction, and the learner to identify and

131 recommend the instruction delivered to the learner. Adaptive learning includes a pro-
132 gram that branches out into different pathways based on user feedback. Without the use
133 of AI, these pathways would be predesigned, and delivery decisions would be based on
134 outcomes of assessments. AI enables us to individualize learning by identifying areas
135 where learners are deficient and by creating pathways focusing on that content (Brusi-
136 lovsky and Peylo 2003).

137 Purpose of this systematic review

138 While the previous reviews have mostly focused on the learner model, in this review, we
139 also emphasize the instructional model along with the content model for adapting instruc-
140 tional content. Specifically, we examine the adaptive strategy used in adjusting the instruc-
141 tion. The purpose of this study is to synthesize the current decade of research on adaptive
142 learning from 2009 to 2018, focusing on adaptive strategies in the Learner Model, Instruc-
143 tional Model, and Content Model in addition to examining publication trends, publication
144 context, research methods, focus, and adaptive technologies. Motivating this review is an
145 interest in understanding emerging trends in the research aims within adaptive learning as
146 well as the techniques researchers are using to produce meaningful evidence associated
147 with adaptive processes. Thus, the study is guided by the following three descriptive and
148 three operational questions:

- 149 (1) What are the publication trends of adaptive learning research? (Journals and years of
150 publication, number of articles published, and journals that publish adaptive learning
151 research)
- 152 (2) What is the context of adaptive learning research published? (Instructional setting,
153 countries represented, subject areas represented, and participant demographics)
- 154 (3) What research outcomes, research design, and data collection methods are used in the
155 studies reviewed?
- 156 (4) What is the focus of research on adaptive learning studies?
- 157 (5) What adaptive strategies are used in the adaptation of instructional content based on
158 the learner model, content model, and instructional model?
- 159 (6) What are the adaptive technologies used in the research published?

160 Furthermore, we strive to evaluate the extent to which the nature of adaptive learn-
161 ing research foci (i.e., content areas and variables) are bounded by the research designs
162 and tools to identify possible intersections for broadening the evidence base through
163 collaboration.

164 Methods

165 The study follows the five-step systematic review process described in the U.S. Department
166 of Education, Institute of Education Sciences (2017), What Works Clearinghouse Proce-
167 dures and Standards Handbook, Version 4.0 (2017): (a) developing the review protocol, (b)
168 identifying relevant literature, (c) screening studies, (d) reviewing articles, and (e) report-
169 ing findings.

170 Data sources and search strategies

171 Two education databases, Education Research Complete and ERIC, were searched using
172 the keyword “adaptive learning” for published articles between the years 2009 and 2018.
173 The focus on these two databases and a narrow choice of terminology were intentional to
174 limit attention to the context of educational research and educational aspects of adaptive
175 learning systems development. Our intention was to exclude articles that only focused on
176 computer science and engineering literature that concentrated on the technical aspects of
177 adaptive learning.

178 Inclusion/exclusion criteria

179 To be included in this systematic review, each study had to meet the screening criteria
180 described in Table 2. A research study was excluded if it did not meet one or more of the
181 criteria. Furthermore, we defined Adaptive Learning for the inclusion of articles as: “*An*
182 *emerging learning technology that dynamically adjusts instructional content to provide*
183 *interactive and personalized learning paths to the individual to facilitate learning.*”

184 Process flow of the systematic review

185 The systematic process followed PRISMA guidelines proposed by the Ottawa Methods
186 Center for reporting items for systematic reviews and meta-analyses (Moher et al. 2009).
187 Figure 2 shows the process flow employed in this study for identification, screening, eligi-
188 bility, and inclusion steps of the process.

189 Coding of data and interrater reliability

190 The research team developed and used a Google coding review form to record the key
191 variables, which are described in Table 3. Research elements were coded using the Google
192 form by two post-doctoral researchers. Initially, each researcher independently coded 10%
193 of the articles, with training and periodic discussion. The lead researcher then calculated
194 the percent agreement on these 10% of dually coded articles. Agreement between the two
195 researchers was 89%. Agreement for the initial sample was somewhat lower for certain
196 variables, mainly when multiple options were available (e.g., research outcome or ethnic-
197 ity). For research outcome, an agreement of 71%, consistency was achieved on one or more
198 specific variables in the sample, but the full list did not consistently match. For ethnicity,
199 where agreement in the initial sample was 50%, the disagreement was determined to be
200 rooted in procedures. For example, in two instances, one rater felt the ethnicity was not
201 explicitly stated in the text, and the other thought it was implied by the study location (e.g.,
202 South Korea). Any items with discrepancies were discussed to calibrate the raters on pro-
203 cedures, and a consensus was achieved before further coding. Once there was agreement
204 on the coding established through this calibration process, the remaining 90% of articles
205 were equally divided and coded by the post-doctoral researchers. The coders met monthly
206 with the lead researcher to address specific coding questions.

Table 2 Inclusion/exclusion criteria

Criteria	Inclusion	Exclusion
Publication date	2009–2018	Prior to 2009 and after 2018
Publication type	Scholarly articles of original research from peer-reviewed journals	Book chapters, technical reports, dissertations, or proceedings
Focus of the article	Articles focused primarily on adaptive learning for instruction	Articles did not include adaptive learning for instruction
Research method and results	There was an identifiable method and results section describing how the empirical study was conducted and the findings. Quantitative and qualitative methods were included	Reviews of other articles, opinion, or discussion papers that do not include a discussion of the procedures of the empirical study or analysis of data such as product reviews or conceptual articles
Language	Journal article was written in English	Other languages were not included

Fig. 2 PRISMA process flow-chart of the adaptive learning systematic review

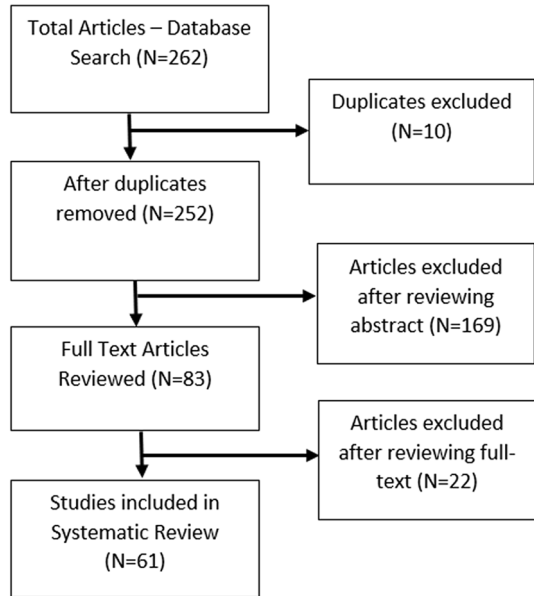


Table 3 Description of the coded elements for each research study

Element	Description
Article information	Full reference including author(s), year of publication, article title, and journal name
Participant demographics	Number of participants in the study, gender, age, ethnicity, and country
Context	Instructional setting coded as K-12, higher education, government, healthcare, military, or business and industry. K-12, subject area, country, and study duration were coded as open ended
Research focus	Coded as an open-ended item
Research outcome	Coded as cognitive, affective, behavior, and other. Cognitive focused on thought, affective focused on feelings and behavioral focused on interactions. “Other” option was also included for those articles that focused on other outcomes
Research design	Codes included experimental, nonexperimental, single-case, and qualitative. A study could have more than one method such as mixed methods or multi-method studies with both a quantitative and a qualitative component
Data collection	Coded as interview/focus group, observation, survey, portfolio, email, chat session transcripts, test data, and other
Adaptive technology	Coded as an open-ended item
Adaptive strategy	Coded as an open-ended item into the learner model, content model, or instructional model

207 Data analysis

208 Descriptive tables, including frequency and percentage, were generated for publication
 209 trends, context, and research methodological components. Narrative data for research
 210 focus, adaptive technologies, and strategies were collapsed into categories by identifying

211 like themes. Once cleaned and collapsed into categories, descriptive statistics, including
212 frequency and percentages, were used to describe each of the coded elements. Examples
213 for each of the themes were also identified in the table.

214 Results

215 The first three sections provide descriptive statistics on adaptive learning research based on
216 publication trends, context, and research methodology components aligned with the first
217 three research questions. We then present results associated with the various parts of the
218 adaptive learning model which align to the final three research questions on research focus,
219 adaptive strategies, and technologies.

220 Publication outlets and trends

221 Journals, frequency of adaptive learning research published, and the number of articles
222 published by year in the last decade are provided in Table 4 and Fig. 3 below. *Computers*
223 *and Education* published the greatest number of articles in adaptive learning and, overall,
224 the most number of articles were published in 2015. During the past decade, there has been
225 an increasing presence of adaptive learning articles published in the educational research
226 focused journals.

227 Instructional context, location and participant demographics

228 The sector in which the studies were conducted and study duration are presented in Table 5.
229 The majority of the studies were conducted in higher education.

230 There is a wide distribution of country origin, with a concentration of adaptive learning
231 articles being conducted in Taiwan and the United States (See Table 6). Nearly half the
232 adaptive learning studies are from one of these two countries.

233 The second research question also considers the subject area (See Table 7). Adaptive
234 learning research has a concentration in computer science and the sciences. Naturally, the
235 focus of computer science was present most often, though generally speaking, there was a
236 wide distribution of subject areas present in the collection of studies.

237 Participant demographics

238 All 61 studies (100%) reported the number of participants in the study. The sample size of
239 the articles ranged from 8 to 15,444 participants with a median of 108 participants. Only
240 21 (34.4%) studies reported gender, which identified 2034 male and 1735 female partici-
241 pants. Only 16 (26.2%) studies reported age or age ranges. Of the 16 studies, only seven
242 studies reported average age of the participants which ranged from 14.2 to 22.0, and the
243 mean of which was 16.9. In the studies that provided age ranges, only two studies had K-12
244 participants and the other seven studies included participants who were above 18 years of
245 age. Only nine studies included ethnicity details for participants. Of the nine, two studies
246 indicated ethnicity as Taiwan or European which was the country/region rather than the
247 ethnic background of the participants.

Table 4 Journals and frequency of publication of adaptive learning research

	Number of studies	Percent
Computers & Education	12	19.67
Computer Applications in Engineering Education	6	9.84
Educational Technology & Society	4	6.56
International Journal of Emerging Technologies in Learning	4	6.56
British Journal of Educational Technology	3	4.92
Education and Information Technologies	3	4.92
Interactive Learning Environments	3	4.92
Journal of Education for Business	2	3.28
Journal of Education Research	2	3.28
Journal of Interactive Media in Education	2	3.28
Online Learning	2	3.28
Australasian Journal of Educational Technology	1	1.64
Contemporary Educational Technology	1	1.64
Decision Sciences Journal of Innovative Education	1	1.64
Educational Technology Research and Development	1	1.64
Educational Sciences: Theory and Practice	1	1.64
International Education Studies	1	1.64
International Journal of Continuing Education and Lifelong Learning	1	1.64
International Journal of Mechanical Engineering Education	1	1.64
Journal of Biological Education	1	1.64
Journal of Computer Assisted Learning	1	1.64
Journal of Educational Psychology	1	1.64
Journal of Information Systems Education	1	1.64
Journal of Research in Science Teaching	1	1.64
Perceptual & Motor Skills: Learning & Memory	1	1.64
ReCALL	1	1.64
Technology Knowledge Learn	1	1.64
The Journal of International Association of Special Education	1	1.64
Turkish Online Journal of Educational Technology	1	1.64

248 Research methodological components

249 The 61 studies were coded for their research outcomes, design, and data collection meth-
 250 ods. The results are presented in Table 8. A majority of the studies (i.e., 67.2%) targeted
 251 cognitive as the outcome variable and used an experimental design. Though more mod-
 252 est, it is noteworthy that more than a third of the studies targeted affective outcomes (i.e.,
 253 37.7%) and even more focused on behavioral outcomes (i.e., 41.0%). Cognitive outcomes
 254 were concerned with thought, affective outcomes focused on feelings, and behavioral tar-
 255 geted interactions (Jhangiani et al. 2014). An “Other” option was also included for those
 256 articles that focused on other outcomes. In some cases, multiple outcomes were listed.
 257 Not too surprisingly, test data and surveys were commonly used for data collection and
 258 occurred in approximately two-thirds of the studies. Extant data, including emails and dis-
 259 cussions, also appeared frequently. The percentages in Table 8 do not add up to 100% for

Frequency of Publications on Adaptive Learning

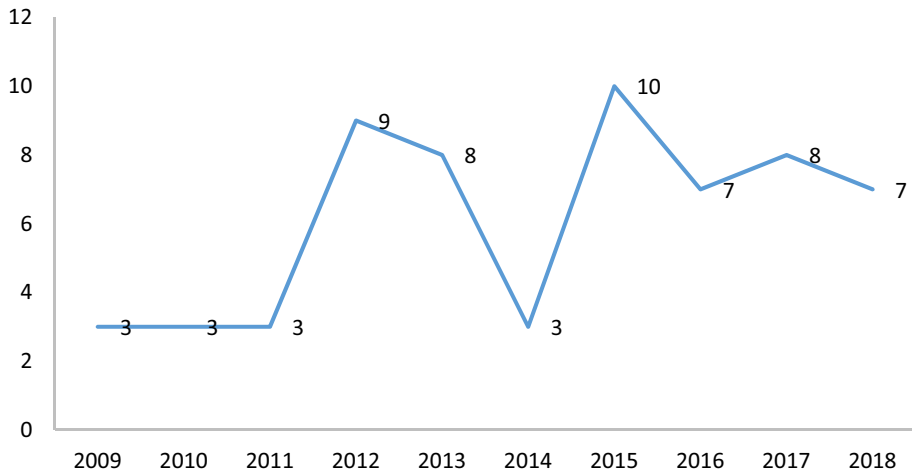


Fig. 3 Frequency of publications on adaptive learning by year

Table 5 Instructional context of adaptive learning research publications

	Number of studies	Percent
<i>Instructional sector</i>		
Government	1	1.6
Healthcare	1	1.6
Higher ed	41	67.2
K-12	16	26.2
Other	2	3.3
	61	100%
<i>Study duration</i>		
Years/semesters	9	14.7
Weeks/months	17	27.9
Hours	3	4.9
Not specified	32	52.5
	61	100%

260 each of the categories, outcomes, designs, and data collection methods as each study could
 261 have multiple outcomes, designs, and data collection methods.

262 Research focus

263 The studies reviewed were coded for their research focus (See Table 9). These studies were
 264 coded using inductive coding. Four focus areas emerged during the coding process: (1)
 265 needs assessment for adaptive learning, (2) examining learner characteristics in adaptive
 266 learning, (3) design and development of adaptive learning systems, and (4) implementation

Table 6 Countries represented in adaptive learning research publications

Country	Number of studies	Percent
Taiwan	18	29.5
United States	11	18.0
United Kingdom	4	6.6
Not provided	3	4.9
Australia	2	3.3
India	2	3.3
Saudi Arabia	2	3.3
Serbia	2	3.3
Spain	2	3.3
Turkey	2	3.3
Canada	1	1.6
Germany	1	1.6
Greece	1	1.6
Greece/Cyprus	1	1.6
Indonesia	1	1.6
Ireland	1	1.6
Italy	1	1.6
Morocco	1	1.6
Netherlands	1	1.6
P. R. China	1	1.6
Republic of Macedonia	1	1.6
Slovenia	1	1.6
South Korea	1	1.6

Table 7 Subject areas of adaptive learning research

Subject	Number of studies	Percentage
Computer science	16	26.2
Sciences	7	11.5
Business	7	11.5
Not specified	7	11.5
English	5	8.2
Education	5	8.2
Engineering and technology	5	8.2
Multiple subjects	4	6.6
Mathematics	3	4.9
Psychology	1	1.6
Pharmacy	1	1.6

267 and evaluation of adaptive learning systems. About an equal number of studies examined
 268 the design and development and implementation and evaluation of adaptive learning sys-
 269 tems. Less emphasis was placed on learner characteristics, and only two needs assessment
 270 studies were present.

Systematic review of adaptive learning research designs,...

Table 8 Research methodological components (outcome variables, research design and data collection methods) in adaptive learning studies

Research methodological components	Number of studies	Percentage
<i>Outcome variables</i>		
Cognitive (e.g., achievement)	41	67.2
Affective (e.g., attitude)	23	37.7
Behavior (e.g., time spent)	25	41.0
Other	6	9.8
<i>Research design</i>		
Experimental	27	44.3
Non-experimental	11	18.0
Qualitative	6	9.8
Mixed-method	17	27.9
<i>Data collection methods</i>		
Test data	43	70.5
Survey	40	65.6
Extant data (Email, recording, discussion data)	25	41.0
Interview	9	14.7
Observation	5	8.2
Clickstream data/log files	4	6.6

Table 9 Research focus in adaptive learning research

Research focus	Number of studies	Percentage
Needs analysis for adaptive system	2	3.28
Focused on learner characteristics	13	21.31
Design and development of adaptive learning systems	24	39.34
Implementation and evaluation of adaptive learning systems	22	36.07

271 Adaptive strategies

272 The adaptive strategies were coded based on the adaptive learning framework that includes
 273 Learner Model, Content Model, and Instructional Model. *Learner Model* refers to the
 274 learner characteristics such as learner attributes, learner knowledge and proficiency, learner
 275 behavior, learner preferences, and individual differences that are used to adapt the con-
 276 tent. *Content Model* refers to the knowledge base for the course and includes components
 277 such as a learning map. *Instructional Model* refers to the techniques including pacing, for-
 278 mat, and sequencing that assist in adapting the instruction based on the content and learner
 279 model. While there were several studies that had more than one model, there were at least
 280 five studies that did not describe their adaptive strategy.

281 From the studies reviewed, ten different learner characteristics were identified as part
 282 of the learner model (See Table 10). Some studies used more than one learner character-
 283 istic. The instrument or the source of measuring learner characteristic is also included in
 284 the table. Learning styles was the most frequently studied learner characteristic followed

Table 10 Adaptive source (learner characteristics) in adaptive framework

Learner characteristics	Number of studies	Adaptive source measuring learner characteristics
Learning style	14	Felder-Silverman Learning Style Model, VARK Questionnaire, Kolb's learning style inventory, Solomon and Felder ILS inventory, Keefe's learning style test
Cognitive style and thinking style	8	Sweller van Merriënboer and Paas, Pask's Holist-Serialist dimension, Witkin's GEFT test, Student preferences for content and components
Learner prior knowledge and background knowledge	8	Pretest, knowledge test, psychological tests for initial comprehension level
Learner knowledge and metacognitive knowledge	6	Content result, semantic description
Learner preference	4	Ignatian teaching methods
Learner behavior	3	Time spent
Learner profile	3	Log data
Learner ability	2	Proficiency level
Multiple learner characteristics	2	Learner needs and personal characteristics, self-efficacy and learning efficiency
Learner interest	1	Student interest survey

285 by Cognitive Styles and Thinking Style, and Learner Prior Knowledge and Background
286 Knowledge.

287 The studies reviewed were coded for adaptive targets, which are a combination of the
288 content model and instructional model, and can be described as what was adapted. Ten
289 different adaptive targets were found and presented in Table 11. As seen in that table, Con-
290 tent, Assessment, Navigation, and Presentation were adapted in the studies reviewed.

291 Adaptive technologies

292 Our analysis in this systematic review indicated that the majority of the selected studies
293 involved the application, design, development, implementation, and evaluation of an adap-
294 tive learning system or platform, depending on the terminology being used, to personalize
295 learning paths. Drawing on our definition of adaptive technology in this systematic review,
296 we classified the employed adaptive technology into four categories: (1) adaptive learning
297 system, (2) adaptive learning application, (3) adaptive teaching approach, and (4) adap-
298 tive design. The operational definitions of the various categories are presented in Table 12
299 along with the distribution of studies across these categories. Most of the studies (73.8%)
300 were categorized at the system or platform level. Only a handful of studies employed adap-
301 tive learning applications, adaptive teaching approaches, or adaptive design solutions.

302 Discussion

303 Comparison of findings from previous reviews to this review

304 In the present study, we examined 61 empirical studies published from 2009 through 2018.
305 By reviewing them, we identified the current trends and patterns of adaptive learning,
306 particularly through the lens of educational research. Similar to previous review studies
307 (Kumar et al. 2017), analysis of this review demonstrated emerging publication trends,
308 instructional contexts, presented context areas, participants' demographics, and methodo-
309 logical components in varied formal and informal learning environments. Findings of our
310 review further indicated a research focus on adaptive learning in the educational research

Table 11 Adaptive targets (content and instructional characteristics) in adaptive learning environments

What was adapted?	Adaptive target	Number of studies
Content	Adaptive content	9
Assessment	Adaptive feedback	8
Assessment	Adaptive course topic and question difficulty	4
Navigation	Adaptive learning sequence	5
Navigation	Adaptive learning path	5
Navigation	Adaptive pacing	1
Navigation	Adaptive navigation	1
Presentation	Adaptive caption filtering	1
Presentation	Adaptive material format and presentation	4

Table 12 Categorization of the employed adaptive technology

Category	Definition	Number of studies	Percent (%)	Examples
Adaptive learning system	Refers to the use of existing adaptive learning systems, or the design, development, implementation; or evaluation of an adaptive learning system for distinct disciplinary or subject learning; or a specific platform that provides structured learning activities or sequenced learning paths; or for the purpose of targeting a specific learning population	45	73.8	Adaptive grading/learning system (AGLS); IC(3) Mentor platform; Learning program for the development of children with autism (LPDCA) learning platform; Realizeit; TECH8 TERENCE; Ubiquitous teaching assistant (u-TA)
Adaptive learning application	Refers to the system or platform's adaptability for the learners to control specific learning activities or paths; or for the purpose of carrying out adaptive learning via different types of learning platforms such as game-based, Web-based, or mobile application	3	4.9	E-school; adaptive game-based learning (GBL) application
Adaptive teaching approach	Refers to the teaching practice of using a specific adaptive learning system or technology; the control techniques of combining other skills or developing a sequenced algorithm to provide personalized instruction or learning scenarios; the strategies generated from assessing learner needs or teacher perspectives	6	9.8	A multimedia-based English pronunciation learning system using corpus technology; adaptive self-explanation prompts model; CT (critical thinking)-infused adaptive English literacy instruction utilizing a Moodle system
Adaptive design solution	Refers to the creation of adaptive learning environments using an existing framework or paradigm; the generation of algorithms for personalized learning path; the consideration of assessing students' learning styles or needs; or the teaching and learning techniques generated through developing evaluative instruments	7	11.5	Adaptive hierarchical questionnaire (AH-questionnaire); Algorithm for the adaptive learning process; using Generic Service Integration framework in adaptive learning experiences using IMS learning design

311 horizon, which included needs analysis for adaptive systems, learner characteristics, the
312 design and development of adaptive learning systems, and the implementation and eval-
313 uation of adaptive learning systems. These findings contribute to the previous literature
314 review studies of adaptive learning through a broad educational lens instead of focusing on
315 specific variables such as the users' personal traits, learning styles, or individual character-
316 istics (Kumar et al. 2017; Nakic et al. 2015; Normadhi et al. 2019).

317 Our study did not address the specific evaluation of effectiveness of adaptive learning.
318 However, by juxtaposing these chosen studies using the framework proposed by Shute and
319 Towle (2003), analysis of our review concentrated on the Learner Model, Content Model,
320 and Instructional Model to address the questions of how to adapt and what to adapt in
321 the employed adaptive learning systems or procedures. These findings further contribute
322 to •Vandewaetere et al.'s (2011) study that specifically focuses on the value of the Learner
323 Model in computer-based adaptive learning environments. In addition, we further classi-
324 fied ten learner characteristics in the adaptive frameworks and ten adaptive targets in the
325 learning environments that would be beneficial to the design, development, and implemen-
326 tation of existing or new adaptive learning systems or adaptive techniques. As such, we
327 contextualized individual personal traits or learning styles as critical attributes of adaptive
328 learning into more measurable variables using educational instruments such as test inter-
329 vention or system log data (Verdú et al. 2008).

330 **Research context and methodological components**

331 Our analysis revealed that there is an increase in the number of adaptive learning studies
332 conducted within various educational settings; however, there is a need for more studies in
333 diverse contexts. Currently, the majority of the studies were conducted in higher education,
334 and, in terms of country, studies in Taiwan were the most prevalent followed by the United
335 States. These findings demonstrate the need for more studies to be done globally and in
336 other instructional settings, such as K-12 classrooms and informal settings. This gap could
337 be due to the faster growth of technology adoption and online learning in higher educa-
338 tion in comparison to other settings. Naturally, higher education learners are more prepared
339 for self-regulated learning and the context that supports adaptive learning. In addition,
340 academic-based researchers may have fewer limitations on gaining access to data within
341 higher education as compared to K-12 or informal settings. The content areas of adaptive
342 learning covered in these studies are broad, such as computer sciences, engineering, lan-
343 guage learning, biology, business, earth sciences, and educational technology. However,
344 data collection methods mainly focused on the use of tests and surveys, and predominately
345 were part of experimental design studies. This analysis indicated that a greater diversity
346 of methodology in this research area is needed to seek a deeper and more comprehensive
347 understanding of the use of adaptive learning.

348 **Instructional design phases in adaptive learning research**

349 The studies in this review were categorized into four groups based on their research focus:
350 (1) needs assessment for adaptive learning, (2) examining learner characteristics in adap-
351 tive learning, (3) design and development of adaptive learning systems, and (4) implemen-
352 tation and evaluation of adaptive learning systems. The studies reviewed are distributed
353 among all the phases of the instructional design process to include analysis, design and

354 development, and implementation and evaluation. A majority of the studies focused on
355 design and development and implementation and evaluation, whereas only two studies
356 focused on analysis.

357 Design and development studies focused on learners, content, or design of instruction.
358 Some of the studies when designing instruction focused on learners such as adapting to
359 learners' preferences, using learner characteristics and self-efficacy in developing an adapt-
360 tive platform, using users' collective intelligence to estimate learners' abilities for select-
361 ing adaptive materials, accommodating individual differences, and using personalized fea-
362 tures and knowledge levels and cognitive styles (●Bower 2016; ●Hammami and Mathkour
363 2013; ●Hsu 2012; ●Huang and Shiu 2012; ●Mampadi et al. 2011; ●Sfenrianto et al. 2018;
364 ●Tseng et al. 2008; ●Wang and Liao 2011; ●Yang et al. 2013a; ●Zafar and Albidewi 2015).
365 Some studies focused on content when designing to increase reading and listening compre-
366 hension, pronunciation learning, and English as Foreign Language (●Cecilia et al. 2016;
367 ●Hsu 2015; ●Mei et al. 2017; ●Wang 2016), whereas other studies focused on instruction
368 to examine effective collaboration, communication and interactions in the system, the use
369 learning management system functionalities in adaptive learning environment design, and
370 design to increase feedback (●Huang and Yang 2009; ●Jonsdottir et al. 2015; ●Matthews
371 et al. 2012). The distribution of studies shows that all of these are essential in the design
372 of adaptive learning. There were also several studies focusing specifically on learner char-
373 acteristics. These studies examined students' learning behavior such as comparing stu-
374 dent thinking styles with their behavior, using web log mining to capture learner behavior,
375 examining learning styles in an adaptive game, comparing student characteristics and their
376 learning paths, and classifying students based on learning styles (●Fasihuddin et al. 2017;
377 ●Jong et al. 2012; ●Kolekar et al. 2017; ●Liu et al. 2017a; ●Soflano et al. 2015; ●van Seters
378 et al. 2012; ●Ortigosa et al. 2010).

379 Implementation and evaluation-focused studies examined learning effectiveness or sys-
380 tem effectiveness. The studies measuring learning effectiveness focused on learner expe-
381 riences; participant flow and navigation; learner negotiation of content and assessment;
382 affective, behavioral, and cognitive reactions to the system; examining critical thinking
383 through collaborative activities; student scientific reasoning; and learning and perfor-
384 mance outcomes based on personalization (●Chou et al. 2015; ●Da-le-Fuente-Valent et al. **AQ6**
385 2011; ●Dziuban et al. 2016; ●Premlatha et al. 2016; ●Salahli et al. 2013; ●She and Liao
386 2010; ●Soflano et al. 2015; ●Walkington 2013; Yang et al. 2014). The studies on system
387 effectiveness focused on system quality, communication (interaction between teachers
388 and students), and course structure; the instruction design for the system and choice of
389 media experience; system's user-friendliness; adapting system features; and adaptability
390 and effectiveness of the system (●Griff and Matter 2013; ●Liu et al. 2017a, b; ●Marković
391 et al. 2013). When using an educational technology such as adaptive learning, it is essential
392 to study both the learning effectiveness as well as the system effectiveness. This can be
393 achieved by examining the learner model (adaptive source) and content and instructional
394 model (adaptive target) (●Vandewaetere et al. 2011). However, not all studies focused on
395 measuring both the learning and system effectiveness.

396 Though there were only two studies specifically focusing on needs assessment, a quali-
397 tative study focusing on elementary school student needs with learning disabilities, and
398 a study examining the requirements for an adaptive learning system (●Polat et al. 2012;
399 ●Neubrand and Harms 2017). The studies examining learner characteristics could also
400 be considered as part of the needs assessment, as it informs the learner analysis in the
401 design and development of adaptive learning. Nevertheless, the fact that the predominant
402 focus of adaptive learning studies was on design and development and implementation and

403 evaluation issues highlights a relative inattention to understanding the needs of instructors
404 with respect to adaptive learning.

405 **Adaptive strategies**

406 For adaptive strategies, the studies were coded based on the learner, content, and instruc-
407 tional model.

408 **Adaptive source**

409 The learner characteristics in the learner model provided the source of adaptation. Ten dif-
410 ferent types of learner characteristics were found in the studies that were reviewed: (1)
411 learning styles, (2) cognitive styles and thinking style, (3) learner prior knowledge and
412 background knowledge, (4) learner knowledge and metacognitive knowledge, (5) learner
413 preference, (6) learner behavior, (7) learner profile, (8) learner ability, (9) learner self-
414 efficacy and efficiency, and (10) learner interest. The various learner characteristics can
415 be classified as cognitive, behavioral, and affective characteristics. This is similar to what
416 •Vandewaetere et al. (2011) found nearly a decade ago in their study on learner charac-
417 teristics in developing computer-based adaptive learning environments. A majority of
418 the learner characteristics are cognitive and include cognitive styles and thinking styles,
419 learner prior knowledge and background knowledge, and learner knowledge and metacog-
420 nitive knowledge. The behavioral learner characteristics include learner preference, learn-
421 ing styles, and learner profile, while affective characteristics include learner ability, learner
422 self-efficacy, and learner interest. It is important to consider the various learner character-
423 istics, including behavioral, cognitive, and affective characteristics, during the assessment
424 of assessing needs. Learning styles was the mostly examined learner characteristic. Though
425 there are mixed findings in the literature on the validity of using learning styles (Kumar
426 et al. 2017), this review assisted in also identifying the various measures that were used in
427 examining learning styles. There were five different instruments used in studying learning **AQ7**
428 styles: (1) the Felder-Silverman learning style model, (2) VARK questionnaire, (3) Kolb's
429 learning style inventory, (4) Solomon and Felder ILS inventory, and (5) Keefe's learning
430 style test. Closer examination of the instruments and the similarities and differences along
431 with their validity might be helpful when studies examine learning styles. Cognitive styles,
432 thinking style, and learner prior knowledge and background knowledge were also exam-
433 ined in a number of studies. Along with learning styles, these are also important in learner
434 analysis to understand the learner needs before the instructional material is designed and
435 adapted to meet the needs of the learner.

436 **Adaptive targets**

437 The adaptive targets are ways in which adaptation occurs and were part of the content and
438 instructional model. •Vandewaetere et al. (2011) differentiate the adaptive targets into con-
439 tent, presentation and instruction, and content and presentation/instruction. In this study,
440 we classify such targets based on the adaptivity as adaptive content, adaptive assessment,
441 adaptive presentation, and adaptive navigation. Several studies only listed content as the
442 source of adaptation and did not specify which aspect of content was adapted, while other
443 studies specified the adaptive target. Adaptation of assessment and navigation were the

444 most commonly examined adaptive targets, and about 10% of the studies focused on adap-
445 tive presentation.

446 Adaptive feedback was examined in several studies. Some of the studies examining
447 adaptive feedback focused on students' current understanding of concepts and reasoning
448 and then providing feedback (●She and Liao 2010); learning the responses from the stu-
449 dents and providing feedback (●Matthews et al. 2012); and reviewing mistakes students
450 made, finding the reasons for their mistake, and providing feedback (●van Seters et al.
451 2012).

452 Adaptive navigation was another adaptive target that was examined in several studies.
453 Some of the studies examining adaptive navigation included examining types of navigation
454 such as map or index (●Mampadi et al. 2011), identifying the learning path based on a set
455 of questions (●Liu et al. 2017a, b), and based on student performance (●Liu et al. 2017a,
456 b). Though only used in only about 10% of the studies, adaptive presentation focused on
457 content format and presentation in terms of different modalities (Tortorella and Graf 2017;
458 ●Louhab et al. 2018). Based on this review, all three aspects of adaptive targets: (1) adap-
459 tive navigation, (2) feedback, and (3) presentation are important in the design of adaptive
460 learning.

461 Adaptive technologies

462 Drawing on the identified adaptive learning techniques, we categorized four types of adap-
463 tive learning technologies: (1) adaptive learning system, (2) adaptive learning applications,
464 (3) adaptive teaching approach, and (4) adaptive design solutions. Concurring with previ-
465 ous studies such as Kumar et al. (2017) and ●Liu et al.(2017a, b), our analysis revealed
466 that the majority of the selected studies involved the use of an existing adaptive learning
467 system or the design, development, implementation, and evaluation of an adaptive learn-
468 ing system, platform, or model, to personalize learning paths. Less than 5% of the studies
469 achieve adaptive learning by emphasizing the use of adaptive learning applications, such
470 as controlling specific learning activities for learners either through specific adaptability of
471 a system or platform or through different types of learning platforms, such as game-based,
472 web-based, or mobile applications. Among the chosen studies, a few of the adaptive learn-
473 ing systems or applications were examined multiple times using different approaches to
474 assess their perceived value and effectiveness. These findings demonstrate an increasing
475 compatibility of adaptive learning with other emerging types of learning management sys-
476 tems or platforms.

477 In addition, our analysis complements previous review studies by identifying a potential
478 research trend in adaptive learning of focusing on the critical role of teaching *how to learn*
479 and focusing on the creation of effective adaptive learning environments through modify-
480 ing teaching design and strategies in order to meet diverse learners' individual differences
481 in interest, expectancy, and ability (●Wang 2016). For instance, about 20% of the stud-
482 ies focused on the teacher perspective or addressed the use of the Felder and Silverman
483 Learning Style Model (FSLSM) to identify the students' learning styles. This was done not
484 only to emphasize the adaptive teaching and control techniques or developed sequenced
485 algorithms, but also to design specific learning scenarios for prototyping. Less than 10%
486 of the studies indicated an adaptive design solution, such as the creation of adaptive
487 learning environments using an existing framework or paradigm. Other design solutions
488 included the generation of algorithms for personalized learning paths, consideration of the

489 assessment of students' learning styles or needs, and teaching and learning techniques gen-
490 erated through developing evaluative instruments.

491 **Limitations**

492 Limitations of our study are mainly related to the review process. We focused on the data
493 search through two primary educational databases (i.e., Education Research Complete and
494 ERIC) and constrained the search by using "adaptive learning" as the search term, which
495 may have limited the literature selected. Analysis of conference proceedings and disserta-
496 tions would have added to this review. Additionally, our review of the literature focused on
497 published articles only in the past decade and articles in English, so other relevant articles
498 might have been excluded. Also, some of the articles reviewed did not describe the meth-
499 odology and intervention in detail. Several of the articles did not include the demograph-
500 ics, or instructional context. For example, about half of the articles did not include the
501 study duration. All of these issues are limitations or cautions for our findings.

502 **Implications and future research**

503 As noted in prior reviews, there is an ongoing need to improve the rigor and diversity of
504 research in adaptive learning. While we show that the number of adaptive learning studies
505 in education continues to grow, there exist numerous opportunities to grow the knowledg-
506 e-base of adaptive learning research in changing contexts. For example, the vast majority
507 of studies utilized testing data and survey data to quantitatively evaluate adaptive learn-
508 ing interventions; however, relatively few studies addressed understanding how adaptive **AQ8**
509 learning works to produce positive impacts, likely best addressed through more intentional
510 qualitative research practices. Conversely, it appears that there is a positive intentionality to
511 study adaptive learning interventions through experimental designs, which will help iden-
512 tify causal practices. But future meta-analytic studies will be needed to synthesize these
513 effects. In addition, it is important for future studies to examine various aspects of adaptiv-
514 ity and specifically report the adaptive strategies or adaptive technologies that were used.
515 Although not included in our study sample, very few meta-analyses were excluded from
516 our search results.

517 The findings from our study have implications for designers and developers building
518 adaptive learning solutions. The various types of adaptivity features focusing on learners,
519 content, and instruction is important to be provided as an option when designing adap-
520 tive learning. This study also has implications for instructional designers who design adap-
521 tive instructional content and also for instructors who might be using these adaptive solu-
522 tions in their courses, on how various adaptive functionality can benefit their students. For
523 designers, developers, and instructors, it might be beneficial to know that learning can be
524 adapted based on a variety of learner characteristics such as knowledge and meta cognitive
525 knowledge, preference, behavior, profile, ability, and interest. In addition, content (includ-
526 ing presentation, assessment, feedback, and navigation) can be adapted in several ways,
527 such as topic and question difficulty, learning sequence, path, pacing, and material format.
528 Finally, it has implications for researchers to build on the findings from this review. There
529 is a need for more studies examining the content and instructional adaptive characteristics.

530 Conclusion

531 Research on adaptive learning in education has primarily focused on the learner model.
532 We build off •Vandewaetere et al. (2011) to highlight and synthesize important research
533 that focuses not just on the learner model, but also addresses the content and instructional models. We find important diversity within studies that emphasize the adaptive
534 target, both within the instructional model and the content model. This underscores
535 the need for adaptive learning researchers to consider the broader scope of the adaptive
536 learning model to include both the source and target. This will also allow for more
537 attention to be paid to the pathway of adaptation that •Vandewaetere et al. (2011) introduced. Collectively, future studies should focus on the increasing availability and capacities
538 of adaptive learning as a learning technology to assist individual learning and personalized growth.
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541

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544 Compliance with ethical standards

545 **Conflict of interest** The authors declare that they have no conflict of interest.

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547 Articles with bullet (•) are the studies included in the systematic review

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