Learning-by-Teaching in CS Education: A Systematic Review

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Abstract

To investigate the strategies and approaches in teaching Computer Science (CS), we searched the literature reviews in CS education in the past ten years. The reviews show that learning-by-teaching with the use of technologies helps improve student learning. To further investigate the strategies applied to learning-by-teaching, three categories are identified: peer tutoring, game-based flipped classroom, and teachable agents. For each category, we further searched and investigated prior studies. The results reveal the effectiveness and challenges of each strategy and provide insights for future studies.

1. Introduction

STEM education, as suggested by Rodger W. Bybee in his book "The Case for STEM Education: Challenges and Opportunities", should contribute to a STEM-literate society, a general workforce with 21st-century competencies, and advanced research and development workforce focused on innovation [1]. The National Science Teaching Association (NSTA), in a recent Position Statement released in February 2020, emphasized that "STEM is not a curriculum, but rather a way of organizing and delivering instruction" and "helping learners apply their knowledge and skills, collaborate with their peers, and understand the relevance of what they are learning" [2].

In order to motivate learning and increase student engagement and therefore improve learning outcomes, educators have explored a wide range of methodologies for classroom techniques. For example, creating interactive learning environments, creatively planning for direct instruction, involving student activities, research-based methods, gamification, and more, have been discussed over the decades [3]. Learning-by-teaching is one of the proven pedagogical mechanisms that can be traced back to the 1970s [4]. Students are encouraged to comprehend materials to be able to present in the classroom to peer students and the instructor or teach others. Abundant studies reported the effectiveness of learning-by-teaching practice in multiple disciplines. However, this approach is not widely used compared to other approaches, especially in CS education [5].

Since the approach has been evolved for more than 50 years, we are interested in finding the current practices and challenges of using it in CS education. Specifically, as CS education embraces the fastest pace of evolution, the pedagogy would benefit from the use of cutting-edge technologies that enable learning-by-teaching, such as game-based learning environments, immersive virtual learning, and artificial intelligence (AI).

In this study, we first reviewed the literature reviews of learning-by-teaching in CS education. By summarizing and synthesizing the trends and challenges, we identified three categories that are either commonly used or emerging. We then collected individual studies for each category and investigated the recent use or the progress of the methods. Our focus was geared more toward the area of CS education in the hope of helping CS educators achieve teaching excellence. By discussing the current status and challenges of the learning-by-teaching approach applied in CS education, this research intends to contribute insight and provide future directions to the CS education community.

2. Overview of CS Teaching Approaches

Studies have shown that using learning-by-teaching is effective in many aspects. Through interaction and conflict, the approach can benefit both the teacher and the learner on cognitive and social abilities [5]. Several previous literature reviews have investigated existing publications, either across all the disciplines to report the general impact of the pedagogical approach [6], or looking into one specific domain [5, 7, 8, 9] or one specific model of the approach [7, 8, 9].

Using emerging technologies with traditional teaching approaches has been experimented with and led to innovative instructional methods. For example, the game-based learning environment has a positive

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effect on learners' intrinsic motivation, cognitive process, and academic achievements [10, 11, 12]. Artificial intelligence has made its way into online learning to better identify whether an approach works as designed, and whether students' learning performance has improved [13, 14]. Virtual immersive learning environments have been utilized to help encourage collaborative processes and enhance deep learning [15, 16]. A few studies explored new approaches and variations that fall under learning-by-teaching [7, 8, 9], although they do not always claim it as learning-by-teaching. These new approaches and variations, if reviewed and categorized, will provide more insights into the phenomenon.

This study started with reviewing the previous literature reviews of Computer Science Education to identify and categorize the most common teaching approaches. We then examined and categorized the individual studies that are making use of newly evolved technologies. We hope that this study will be able to provide a perspective on future research directions for CS education.

3. Materials and Methods

3.1. Search strategy

The use of the acronym learning-by-teaching was first mentioned in the 1970s, and systematically developed in the 1980s, mainly for language learning back then [4], and then in the STEM field in 2006 [17]. Schulte et al. [17] investigated CS education and revealed that the evolution of technology had affected CS education in many different ways, such as the development of learning materials, class activities, and the tools being used in school [18]. To find out new approaches and studies based on technologies since then, we searched Google Scholar, IEEE Xplore, ACM Digital Library, Scopus (Sage, Springer, Science Direct), PubMed, Taylor & Francis, and Web of Science for publications between the year of 2010-2021. The chosen databases are commonly used in Computer Science education and STEM education. The key search term was "learning-by-teaching" and "review". The references in the included articles were also screened for additional qualified studies.

3.2. Eligibility criteria

Instructional strategies are often intertwined and mixed with each other. For example, depending on how it is implemented, learning-by-teaching is often considered a type of collaborative learning. Although popular collaborative learning methods, such as peer review and team-based learning, may share similar characteristics with certain teaching-by-learning implementations, they cannot be categorized as learning-by-teaching methods due to the fact that they do not explicitly assign students the role of "teacher" or "tutor", or clearly involve them in teaching. With this in mind, we used the following inclusion criteria for the review articles in learning-by-teaching:

- Available in full text
- Written in English
- Journal or Conference papers
- Related to STEM or CS education
- Papers reviewing learning-by-teaching as an instructional method

4. Review of Reviews

By using the keywords "Reviews" and "Computer Science Education" and the time period from 2010 to 2021 in Google Scholar search, 45 papers were returned. The purpose of this search is to find out the common teaching approaches and strategies in CS education, to be the starting point for further investigation.

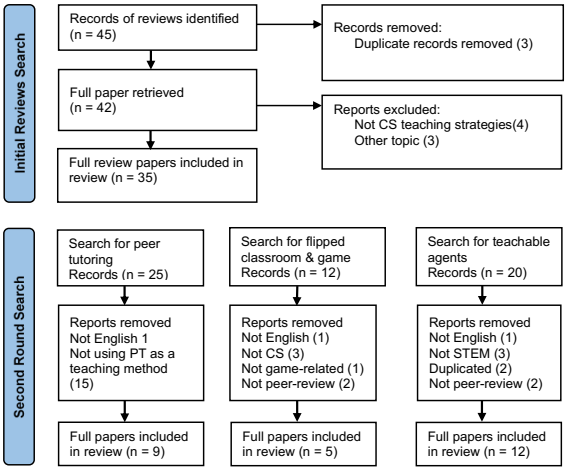

Figure 1. Search flow process

The examination of the papers' titles and abstracts reveals the most common themes as "peer tutoring", "flipped classroom", "game-based", and "teachable agents". Peer tutoring approaches show a positive impact on the learning of both tutor and tutee(s) through bonding and supportive relationships, team spirit, social competence, self-esteem, communication skills, higher achievement, and better productivity.

Flipped classrooms have been widely experimented in secondary and post-secondary teaching institutions as it applies to learning and retention. The applied learning strategies in learning-

by-doing suit introductory courses in computer programming. The approach improves student learning while it may overwhelm students at times.

When it comes to the game-based approach in teaching programming, findings show that educational games add context and fun to learning. Students can relate the elements in games to programming constructs which are usually difficult for students to grasp. Animated game scenarios provide context and stimulate students for high levels of engagement.

The last common keyword, Teachable Agents, is a learning technology that can provide feedback to students and help students learn by using explicit visual representations and environments that support teaching interactions.

5. Further Review of the CS Education Approaches

To further investigate the improvement and new trends in CS education, we decided to extend the review to dig deeper into the three identified methods: flipped classroom, peer-tutoring, and teachable agents. Since CS is tightly connected to the digitalized world, incorporating the traditional learning-by-teaching method with computer-aided agents is worth exploring.

5.1 Peer tutoring (PT)

For the peer tutoring method, we searched the same databases and applied the same search strategies as we did for "learning-by-teaching". The combinations of the keywords we used for peer tutoring articles can be described as:

("peer tutoring" OR "peer teaching") AND
("computer science" OR "programming")

There are multiple definitions of peer tutoring. To keep in line with the theme of our paper – learning-by-teaching, we adopted the definition by [19] that peer tutoring is an instructional method in which one student tutors another student in the same classroom.

Although the search results for peer tutoring are abundant, the majority of them are related to peer tutoring as a support program, particularly in the field of CS education. In these studies, advanced-level students are hired or incentivized to provide tutoring to lower-level students. The peer tutors in this case are not students who are taking the same classes as the tutees. The intention of these peer tutoring programs is to provide general support to a computer science program, or even to an entire college for the purpose of increasing student retention [20, 21, 22, 23, 24]. The peer tutors are not evaluated for their learning performance in a particular subject as the result of being tutors, which in essence, do not conform to learning-by-teaching. In fact, the role of these "peer tutors" is plain "tutors" as they are peers with the tutees in the same course, program, or college.

Since the focus of our review is learning-by-teaching as an instructional method, we eliminated those articles that only use peer tutoring as a support program, and only kept those that implemented peer tutoring or peer teaching in the classroom as a teaching strategy. With this criterion in place, the final total number of articles we selected was reduced to 9, all of which are in higher education settings. Table 1 summarizes the articles selected. Among the articles selected for peer tutoring, 4 of them are peer-reviewed conference papers and 5 of them are peer-reviewed journal papers. As shown in Figure 2, programming is the most popular subject taught using peer tutoring. Other subjects taught in the studies include computer fundamentals, Linux administration, web development, and digital forensics.

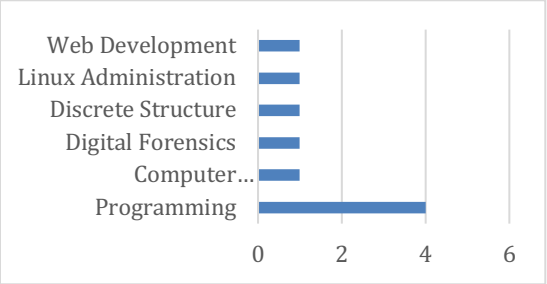

Figure 2. Subjects taught in peer tutoring articles

In regards to research methodology, as shown in Figure 3, four out of the nine papers selected adopted the quasi-experimental design for quantitative research [25, 26, 27, 28]. In these studies, one class was assigned to be the experimental group using peer-tutoring or peer tutoring for teaching, while another class was used as the control group. In general, the studies agreed that peer tutoring has a positive effect on students' attitudes and confidence [25, 27, 28], while [26] did not specifically study students' attitudes and confidence. Three out of the four showed statistical significance in the effect or correlation between peer tutoring and academic performance [25, 26, 28]. The perception of the positive effect of peer tutoring on students' attitude and confidence is further confirmed by other studies using mixed methods [29, 30], convenience sampling [31], and experience reports [32, 33].

It is also worth mentioning that three of the studies also involved external tutors to support student

learning. Both studies from Luca and Clarkson [29] and Govan [33] utilized the tutoring service provided by their programs. Whereas Emurian, et al. [31] utilized an automated computer tutoring program alongside the peer tutoring technique in the classroom.

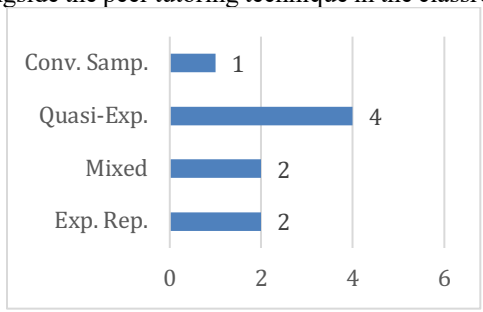

Figure 3. Research methodologies used in peer tutoring articles

5.2 Game-based flipped classroom (FC)

For the flipped classroom method, the typical application in CS education is investigated in the reviews that we identified and summarized in the previous section. With the effort of finding improvements combining with innovative technologies, a review article [34] examined the studies that use game-based learning in a flipped classroom involving multiple subjects. The paper concluded that game-based learning combined with flipped classroom could increase student engagement and motivation.

The combinations of the keywords we used for searching game-based flipped classroom articles can be described as:

("flipped classroom") AND ("game") AND ("computer science" OR "programming" or "CS education")

From the same databases mentioned earlier, nine records were found. After eliminating the ones that are not in English, not related to CS education, or not peer-reviewed, five articles were identified in this category. Table 2 summarizes the approaches and study outcomes reported in these papers.

Four of the five studies conducted empirical studies in the higher education settings to test the effectiveness of incorporating game-based learning environments [35, 36, 37, 38] in CS education. The fifth study was conducted across multiple European countries with college, middle school, and high school students on various subjects [39].

All the four empirical studies mentioned above reported positive results on perception of learning; namely, students increased motivation and satisfaction with the class activities. Three of the studies observed higher performance in the test [35, 36, 37]. Some studies chose existing online game-based platforms such as *Kahoot!* [36, 37] and *Moodle* [37], and some chose to create their own game application [35, 38, 39]. The common challenge for a game-based learning environment is the learning curve for students to learn the interfaces; either it is an existing one, or it is the plan to create a new one. However, this obstacle is relatively easy to overcome when applying in CS education, since students in the CS-related majors are experienced in overcoming the challenges of learning new software and technologies.

5.3 Teachable agent (TA)

The teachable agent method is a relatively new approach. There are not many studies that have been conducted in CS education. No reviews have been found in this category. The method is promising as the National Science Foundation has funded several grant proposals of this type. Therefore, we extended the search to "STEM education". The combinations of the keywords we used for searching game-based flipped classroom articles can be described as:

("teachable agent" OR "teachable agents") AND ("game") AND ("STEM")

From the same databases, 16 records were found. After eliminating the ones that are not in English, not related to STEM education, nor published in peer-reviewed conferences or journals, 11 articles were identified for this category. Table 3 summarizes their approaches and study outcomes. Three studies targeted math, four targeted science (mainly biology), one was on general STEM subjects, and one was related to healthcare, as shown in Figure 4. All the studies identified in this method targeted young kids, from preschool to K-12. The application of teaching agents for higher education needs to be explored for future studies.

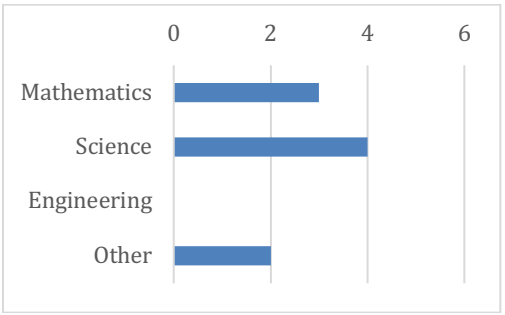

Figure 4. Subjects taught in teachable agent articles

Among the 11 selected articles, ten used 2D or 3D software virtual agents, while two used tangible agents [40, 41]. Muldner, K. et al. [40] combined a projector

and two mobile devices to form a tangible agent with which students can touch and move to interact. Werfel K. et al. [41] proposed an AI robot to facilitate the teaching process. Compared to software-only 2D avatar teaching agents (Tas), the tangible TAs or robot TAs provide immersive reality interactions that can fully promote motivation and increase knowledge retention. The study conducted by Ternblad, E. et al. [42] focused on the misbehavior of children who try to manipulate the TA for the purposes that are not as designed. The result pointed out that although the behavior to outsmart and exploit the TA exists, it is very rare that the misbehavior could harm the entire learning process. Instructors may consider making certain adjustments to decrease this kind of behavior if being detected. The other 11 studies made an effort in the cognitive aspect of the TA, by adding affective or adaptive machine learning or AI features. The results show that interactive TA with intrinsic motivation [43, 44] can motivate students more. Introducing competition where the TAs trained by the students are battling in pairs on solving problems can also increase motivation. Furthermore, Subagdja B. et al. [45] explored the feasibility of using a single TA or multiple TAs at a group level.

6. Discussion

As highlighted by existing literature, learning-by-teaching is an undervalued and underused instructional strategy that has been demonstrated effective in various subject domains such as engineering, pre-service teacher education, and mathematics [5, 46, 47]. In this paper, we focus on three specific instructional methods under the umbrella of learning-by-teaching; namely, game-based flipped classroom, peer-tutoring, and teachable agents. We also investigated their effectiveness in the domain of CS education.

As evidenced in the literature collected and analyzed in this paper, peer tutoring, flipped classrooms, and teachable agents are effective methods in teaching computer science-related subjects.

Among the three approaches, the flipped classroom has seen growing popularity in the past decade, as shown by the number of literature reviews and research articles that we found on the subject. However, compared to other popular pedagogical approaches, there is still a growing space for the flipped classroom in CS education, such as making full use of emerging technologies that CS students are learning to use or develop. Combining a game-based learning environment can be very promising, with the careful design of the materials to avoid the interface learning curves as well as the unintended manipulation of game behavior.

Despite its long-existing history and proven effectiveness, peer tutoring has some challenges in CS education. One common challenge is the use of peer tutoring at the program- or college-level due to the high drop-out rates in the CS courses [20, 21, 22, 23, 24]. Furthermore, peer tutoring in the classroom takes additional effort in planning and classroom management, which may also contribute to the low adoption rate.

Teachable agents, when compared to the other methods, are still in their infancy. However, with the increasing adoption of online learning and the advanced development in AI and its implementation in learning environments, teachable agents have a great potential for more adoption, particularly in CS education, such as teaching different programming languages. The effectiveness of using teachable agents in higher education is yet to be explored. Students can be guided to design their own teachable agent applications or program AI for robot teachable agents.

7. Conclusion and Future Work

In this paper, the reviews about learning-by-teaching methodologies in CS education in the past ten years have been studied. The outcomes and challenges of the approaches were synthesized and summarized. Three specific categories have been identified: game-based flipped classroom, peer-tutoring, and teachable agents. We then extended the review to explore individual studies that fall into the three categories.

Modern tools such as game-based learning and AI assistance pointed out directions for future studies that use learning-by-teaching in CS education. The U.S. Congress passed the STEM Education Act of 2015, which officially made computer science part of STEM, and set computer science for underserved populations as “Absolute Priority 3” [48]. While a lot has progressed since then, including helping the public understand why CS education is relevant and necessary, and realize many accessible tools to teach programming available, there are still challenges, including building a pipeline of teachers who can meet the rising demand for CS in public schools, and making access to CS learning truly equitable in terms of gender, race, and ethnicity [49].

Table 1. Selected articles for peer tutoring

Reference	Pub Type	Subjects	Methodology	Ext. Tutor	Participants	Outcomes
[27]	Conference	Programming	Quasi-Experimental		n=33	Not statistically significant. However, peer tutoring has shown a positive effect on student confidence.
[28]	Conference	Programming	Quasi-Experimental		n=42	Peer tutoring had a positive effect on confidence and performance.
[25]	Journal	Computer Fundamentals	Quasi-Experimental		n=107	Reciprocal Peer Tutoring (RPT) is more effective than direct learning in improving student's learning achievement.
[32]	Conference	Linux Administration	Experience Report		N/A	Peer tutoring encourages active learning. However, the instructor has to monitor and correct the misinformation being shared if necessary.
[31]	Journal	Programming	Convenience Sampling	Yes	n=34	Students had positive ratings of the effectiveness of both the computer tutor program and the collaborative peer tutoring.
[29]	Conference	Web development	Mixed method	Yes	n=110	Strong positive feedback from tutors and high satisfaction with the courses.
[33]	Journal	Digital Forensics	Experience Report	Yes	N/A	Students perceived the peer tutoring activities to be an effective way to develop greater comprehension of the material. They also enhanced their levels of confidence in their own understanding through teaching.
[26]	Journal	Discrete Structures	Quasi-Experimental		n=60	Students exposed to peer tutoring had significantly higher achievements than those in conventional teaching.
[30]	Journal	Programming	Mixed method		n=72	The peer instruction method increases students' self-efficacy more than the traditional teaching method.

Table 2. Selected articles for flipped classroom

Reference	Platform	Methods	Subject	Features	Study Design	Outcomes
[35]	WebGL, Unity	FC with problem-based learning, for motivation and performance.	Programming	Problem-based	Two groups in a 7-week course; focus group with game-based FC, and the control group with video-based learning; Questionnaires and interviews.	The focus group achieved autonomy in online homework outside of class, spent more time thinking of questions for discussion in class, scored higher in the test.
[38]	design pattern framework	Applied all principles of FC and CBL.	Software design	Structural software design patterns, challenge-based learning	A case study of 4 weeks with 42 undergraduate students; No focus vs control group; Self-evaluation survey.	The three patterns of game requirements (Strategy, State, and Observer) had good perceptions of learning

[36]	Kahoot!	Incorporated a gamified student response system with FC.	Object-oriented design	Gamified student response system	A semester-long case study with 25 students; Nine quizzes consisting of 227 questions; six surveys; final course feedback.	The students reached a higher learning effect and motivation, would like more face-to-face lessons, overall satisfied
[37]	Moodle, Kahoot	Gamification supported FC during the coding period; competition and cooperation to improve opinions and attitudes.	Project development	Gamification-supported flipped classroom	A case study of 35 CS students participated during a 14-week course; pre-test and post-test, videos with quizzes.	Most teacher candidates were satisfied with the activities; all increased motivation and in-class competition.
[39]	multiple platform and applications	By investigating educators with systematic survey questions, the study designed a game model for their own application.	Multiple subjects	Adaptive game-based learning	Surveyed five educators from different schools teaching different subjects with game-based FC experience; an adaptive game-based learning environment was designed.	Tested in limited trials with the same participants as the partners. The result was positive that a fully adaptive gaming experience is needed.

Table 3. Selected articles for Teachable Agents

Reference	Methods	Agent type	Subjects	Study design	Outcomes	Notes
[50]	Teachers design learning goals and learning content; game developers develop the game; the students use the system to learn. The design and development iterate during the life cycle of the educational game.	affective TA	Transport in plants in secondary science curriculum	Small scale testing and interview on the three populations for evaluation, no statistical significance analysis	The problems are focused on the tradeoff between the flexibility of user control and the constraints from built-in system settings.	The agent acts as a learning companion for students, while acting as an authoring tool for teachers to design teaching materials
[51]	Used a set of three design principles to guide development; The TAs are intended to improve students' abilities to reason in specific ways, causally or inductively.	Betty's Brain	Hierarchical reasoning in biology for young children	2-year research using Betty's Brain with 153 fourth graders (9-10 year-old children) in their regular science classrooms	TAs provided a way for students to organize the facts they learned from the science kit, which had a leveraging effect on how much they learned.	The agent acts as a learning companion for students, while acting as an authoring tool for teachers to design
[40]	The system uses a projector to display the problem space, a pendaphone to capture the position of the hanging pointer (tangible interface), and an iPod touch interface.	adaptive tangible	Geometry	A pilot study with 4 K-12 students. They took a survey, taught TA how to solve geometry problems, discussed the experience.	Students enjoyed the embodied nature of the TA system, but tangible nature and technologies interfere with learning new concepts which reduced the learning outcome.	physical interaction: move, twist, slide.
[41]	A new research direction exploring robots as TA.	AI robots	General education	Scenarios and challenges, no study	N/A	N/A

[43]	A psychological need modeling approach to enhance the dynamic interactions of TAs with intrinsic motivations	TA with intrinsic motivation in a 3D virtual environment	science: the transport in living things	Field study in middle schoolers. The treatment group of 14 students used TA w/ intrinsic need model the control group of 11 students used TA w/ out intrinsic need model.	Students in the treatment group statistically completed more tasks, obtained better results of learning efficiency and higher scores than the control group.	
[45]	A framework of smart building blocks for multiagent systems.	interactive cognitive TA	healthcare	case study on two different domains: developing autonomous NPCs that roam and interact with user avatars, and several agents act as in-house caregivers.	Teaching can be conducted within a single agent and at a group level to learn interdependencies among different agents in the group.	
[52]	A symbol manipulation method following design conditions. It consists of three parts: teaching, recognition, and test modules.	interactive TA	K-12 math	No empirical study. The development of the system was described.	N/A	
[42]	The presence of behavioral patterns (exploit or outsmart the system) among preschoolers who use a teachable agent-based play-&-learn game in early math.	The misuse of TA	preschooler math	A study involved 43 children; The children played MG in 20-min sessions 2–3 times a week in five consecutive weeks. Behaviors were identified and observed.	Unintentional use of the game did occur, harmful case was rare; unexpected awareness of what it means to learn and to teach.	possible adjustments to decrease gaming-like behavior or insufficient skills/ poor learning
[53]	The TA system incorporates intrinsic motivation in fulfilling three perspectives of educational requirements: Teachability, practicability, affectability.	goal-oriented and motivated	diffusion and osmosis	The treatment group of 12 students used TA through two 45 mins sessions. The control group of 12 learned the same topic on standard classes within the same time.	The TA with intrinsic motivations had more initiative interactions with students, and the overall rating of preference was high	
[54]	Incorporated a "Game Show" feature; online learning; students teach SimStudent, and then the trained SimStudent compete in pairs by solving problems.	online SimStudent	Algebra	141 students, 7 classes with class level randomization. Both teach SimStudent, focus group with the goal of the highest rating, control group with the goal to pass the quiz.	Motivations increased; equation solving proficiency improved; no observed improvement in conceptual understanding	
[55]	Teach animals in a virtual world, targeting children under age 12. The game encourages reflective thinking and conceptual changes.	Animal class with machine learning	Mathematics and Geometry	2718 kids participated for 2 years. The evaluation phase had 3 tasks: learning outcomes, user experience, social networking.	More than half had positive learning outcomes, increased motivation. The presence of the teacher is important.	Competition was the reason to teach. Game is not beneficial for all.

8. References

[1] Bybee, R.W., *The case for STEM education: challenges and opportunities*, National Science Teachers Association, Arlington, VA, 2013.

[2] National Science Teaching Association, "STEM Education Teaching and Learning | NSTA", 2020. https://www.nsta.org/nstas-official-positions/stem-education-teaching-and-learning

[3] Kauchak, D.P., and P.D. Eggen, *Learning and teaching: research-based methods*, Pearson, Boston, 2012.

[4] Frager, S., and C. Stern, "Learning by Teaching", *The Reading Teacher 23*(5), 1970, pp. 403–417.

[5] Carberry, A.R., "A Review of Learning-by-Teaching for Engineering Educators", 2012, pp. 17.

[6] Duran, D., "Learning-by-teaching. Evidence and implications as a pedagogical mechanism", *Innovations in Education and Teaching International 54*(5), 2017, pp. 476–484.

[7] Alegre, F., L. Moliner, A. Maroto, and G. Lorenzo-Valentin, "Peer tutoring in mathematics in primary education: a systematic review", *Educational Review 71*(6), 2019, pp. 767–791.

[8] Bakheet, E.M., and A.M. Gravell, "Would Flipped Classroom be My Approach in Teaching Computing Courses: Literature Review", *2021 9th International Conference on Information and Education Technology (ICIET)*, IEEE (2021), 166–170.

[9] Hendrik, H., and A. Hamzah, "Flipped Classroom in Programming Course: A Systematic Literature Review", *International Journal of Emerging Technologies in Learning (iJET) 16*(02), 2021, pp. 220.

[10] Brezovszky, B., J. McMullen, K. Veermans, et al., "Effects of a mathematics game-based learning environment on primary school students' adaptive number knowledge", *Computers & Education 128*, 2019, pp. 63–74.

[11] Huang, W.-H., "Evaluating learners' motivational and cognitive processing in an online game-based learning environment", *Computers in Human Behavior 27*(2), 2011, pp. 694–704.

[12] Kuo, M.-J., "How does an online game based learning environment promote students' intrinsic motivation for learning natural science and how does it affect their learning outcomes?", *2007 First IEEE International Workshop on Digital Game and Intelligent Toy Enhanced Learning (DIGITEL'07)*, IEEE (2007), 135–142.

[13] Rossi, P.G., "Learning Environment With Elements Of Artificial Intelligence", *Journal of e-Learning and Knowledge Society 5*(1), 2009, pp. 191–199.

[14] Samarakou, M., A. Papadakis, E.D. Fylladitakis, A. Hatziapostolou, G. Tsaganou, and W.G. Früh, "An Open Learning Environment for the Diagnosis, Assistance and Evaluation of Students Based on Artificial Intelligence", *International Journal of Emerging Technologies in Learning (iJET) 9*(3), 2014, pp. 36–44.

[15] Bronack, S., R. Sanders, A. Cheney, R. Riedl, J. Tashner, and N. Matzen, "Presence Pedagogy: Teaching and Learning in a 3D Virtual Immersive World", pp. 11.

[16] Jantakoon, T., P. Wannapiroon, and P. Nilsook, "Virtual Immersive Learning Environments (VILEs) Based on Digital Storytelling to Enhance Deeper Learning for Undergraduate Students", *Higher Education Studies 9*(1), 2019, pp. 144.

[17] Loewus, L., "When Did Science Education Become STEM?", *Education Week*, 2015. https://www.edweek.org/teaching-learning/when-did-science-education-become-stem/2015/04

[18] Schulte, C., M. Hornung, S. Sentance, et al., "Computer science at school/CS teacher education: Koli working-group report on CS at school", *Proceedings of the 12th Koli Calling International Conference on Computing Education Research*, Association for Computing Machinery (2012), 29–38.

[19] Gordon, E.E., *Peer Tutoring: A Teacher's Resource Guide*, ScarecrowEducation, 2005.

[20] Assiter, K., "Experiences Offering an Online Version of Computer Science Support (Peer Tutoring) to Undergraduate Computer Science Majors in the Era of COVID-19", pp. 12.

[21] Cottam, J.A., S. Menzel, and J. Greenblatt, "Tutoring for retention", *Proceedings of the 42nd ACM technical symposium on Computer science education - SIGCSE '11*, ACM Press (2011), 213.

[22] Gerhardt, J., and M. Olan, "Peer Tutoring in Programming: Lessons Learned", 2010, pp. 9.

[23] Made, A.F., and A. Hasan, "Creating a More Equitable CS Course through Peer-Tutoring", pp. 6.

[24] Naghedolfeizi, M., X. Zeng, and C. Dong, "Enhancing Computer Science Program Through Revising Curriculum, Peer Mentoring/Tutoring, and Engaging Students in Undergraduate Research", *2018 ASEE Annual Conference & Exposition Proceedings*, ASEE Conferences (2018), 30426.

[25] Bakare, J., and C.T. Orji, "Effects of reciprocal peer tutoring and direct learning environment on sophomores' academic achievement in electronic and computer fundamentals", *Education and Information Technologies 24*(2), 2019, pp. 1035–1055.

[26] Campit, J.B., J. Cayabyab, and E. Galas, "The Effect of Peer Tutoring on Achievement of Students in Discrete Structures", *3*(5), 2015, pp. 6.

[27] Facey-Shaw, L., and P. Golding, "Effects of Peer Tutoring and Attitude on Academic Performance of First Year Introductory Programming Students", *Proceedings Frontiers in Education 35th Annual Conference*, IEEE (2005), S1E-1-S1E-6.

[28] Golding, P., L. Facey-Shaw, and V. Tennant, "Effects of Peer Tutoring, Attitude and Personality on Academic Performance of First Year Introductory Programming Students", *Proceedings. Frontiers in Education. 36th Annual Conference*, IEEE (2006), 7–12.

[29] Luca, J., and B. Clarkson, "Promoting Student Learning through Peer Tutoring - A Case Study", *ED-MEDIA2002 World Conference on Educational Multimedia,Hypermedia & Telecomunications*, (2002).

[30] Yıldız, T., and Ş. Gündüz, "The Effect of Peer Instruction Method in Programming Education to Student's Attitudes towards Course and Programming Self-Efficacy", *Shanlax International Journal of Education 8*(4), 2020, pp. 50–56.

[31] Emurian, H.H., H.K. Holden, and R.A. Abarbanel, "Managing programmed instruction and collaborative peer tutoring in the classroom: Applications in teaching Java™", *Computers in Human Behavior 24*(2), 2008, pp. 576–614.
[32] Cold, S.J., and G.D. Hickman, "Literature review and experience with whole classroom peer tutoring for IT students", *Procedding of the 8th ACM SIG-information conference on Information technology education - SIGITE '07*, ACM Press (2007), 49.
[33] Govan, M., "The Application of Peer Teaching in Digital Forensics Education", *Innovation in Teaching and Learning in Information and Computer Sciences*, 2014, pp. 1–7.
[34] Algayres, M.G., and E. Triantafyllou, "Combining game-based learning and the flipped classroom: a scoping review", *Proceedings of the 13th International Conference on Game Based Learning, ECGBL 2019*, Academic Conferences and Publishing International (2019), 823–831.
[35] Hsu, W.-C., and H.-C.K. Lin, "Impact of Applying WebGL Technology to Develop a Web Digital Game-Based Learning System for Computer Programming Course in Flipped Classroom", *2016 International Conference on Educational Innovation through Technology (EITT)*, (2016), 64–69.
[36] Dolezal, D., A. Posekany, R. Motschnig, and R. Pucher, "Effects of Introducing a Game-Based Student Response System into a Flipped, Person-Centered Classroom on Object-Oriented Design", *Advances in Web-Based Learning – ICWL 2018*, Springer International Publishing (2018), 132–139.
[37] Hasan, Ã., S. Kanbul, and F. Ozdamli, "Effects of the gamification supported flipped classroom model on the attitudes and opinions regarding game-coding education", *International Journal of Emerging …*, 2018.
[38] Silveira, I.F., "A game development-based strategy for teaching software design patterns through challenge-based learning under a flipped classroom approach", *Anais do XXIV Workshop sobre Educação em …*, 2016.
[39] Algayres, M.G., E. Triantafyllou, L. Werthmann, et al., "Collaborative game design for learning: the challenges of adaptive game-based learning for the Flipped Classroom", *EAI ArtsIT 2020 - 9th EAI International Conference: ArtsIT, Interactivity & Game Creation*, (2021).
[40] Muldner, K., C. Lozano, V. Girotto, W. Burleson, and E. Walker, "Designing a Tangible Learning Environment with a Teachable Agent", *Artificial Intelligence in Education*, Springer Berlin Heidelberg (2013), 299–308.
[41] Werfel, J., "Embodied Teachable Agents: Learning by Teaching Robots", pp. 8.
[42] Ternblad, E.-M., M. Haake, E. Anderberg, and A. Gulz, "Do Preschoolers 'Game the System'? A Case Study of Children's Intelligent (Mis)Use of a Teachable Agent Based Play-&-Learn Game in Mathematics", *Artificial Intelligence in Education*, Springer International Publishing (2018), 557–569.
[43] Borjigin, A., C. Miao, S.F. Lim, S. Li, and Z. Shen, "Teachable Agents with Intrinsic Motivation", *Artificial Intelligence in Education*, Springer International Publishing (2015), 34–43.
[44] Zhao, G., and Z. Shen, "Learning-by-Teaching: Designing Teachable Agents with Intrinsic Motivation", pp. 14.
[45] Subagdja, B., and A.-H. Tan, "Interactive Teachable Cognitive Agents: Smart Building Blocks for Multiagent Systems", *IEEE Transactions on Systems, Man, and Cybernetics: Systems 46*(12), 2016, pp. 1724–1735.
[46] Aslan, S., "Is Learning by Teaching Effective in Gaining 21st Century Skills? The Views of Pre-Service Science Teachers", *Educational Sciences: Theory & Practice*, 2015.
[47] Koh, A.W.L., S.C. Lee, and S.W.H. Lim, "The learning benefits of teaching: A retrieval practice hypothesis", *Applied Cognitive Psychology 32*(3), 2018, pp. 401–410.
[48] U.S. Department of Education, "Science, Technology, Engineering, and Math, including Computer Science | U.S. Department of Education", 2021. https://www.ed.gov/stem
[49] Hoffmann, L., "Tackling the Challenges of CS Education", *Commuinications of the ACM 63*(11), 2020, pp. 160.
[50] Ailiya, C. Miao, and Z. Shen, "Authoring Educational Games through Affective Teachable Agent", *2012 IEEE 12th International Conference on Advanced Learning Technologies*, IEEE (2012), 102–104.
[51] Chin, D.B., I.M. Dohmen, and D.L. Schwartz, "Young Children Can Learn Scientific Reasoning with Teachable Agents", *IEEE Transactions on Learning Technologies 6*(3), 2013, pp. 248–257.
[52] Song, D., "Designing a Teachable Agent System for Mathematics Learning", *Contemporary Educational Technology 8*(2), 2017.
[53] Zhao, M., P. Chen, J. Wang, and L. Yang, "The Practice of the Flipped Classroom Mode in the Information System Security Curriculum", *2018 9th International Conference on Information Technology in Medicine and Education (ITME)*, IEEE (2018), 669–672.
[54] Matsuda, N., E. Yarzebinski, V. Keiser, R. Raizada, G.J. Stylianides, and K.R. Koedinger, "Studying the Effect of a Competitive Game Show in a Learning by Teaching Environment", *International Journal of Artificial Intelligence in Education 23*(1–4), 2013, pp. 1–21.
[55] Ketamo, H., "Learning-by-Teaching in Educational Game: Educational Outcome, User Experience, and Social Networks", pp. 19.