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What Exactly is a Laboratory in Computer Science?

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***Abstract*—This work presents a large scale literature review on the question of what a laboratory in computer science is. This question arises since computer science has different traditions and is thus harder to grasp compared to more traditional fields of study. A total of 83 papers from the IEEE and ACM digital libraries were inductively categorised. All reviewed papers were published between the years 2017 and 2021. The results show that most laboratories are described in the context of teaching (course development and broader education / laboratory pedagogy research). One big problem in current laboratories seems to be that most are described without any didactical concepts, and the didactical concepts described by the included papers cover a wide range of principles. The disciplines of the reviewed laboratories are highly diverse and span across a wide spectrum with most papers either focussing on programming / software development or do not have a specific laboratory description.**

***Index Terms*—computer science education, laboratories, laboratory pedagogy, didactics**

I. Introduction

When we look at STEM education, laboratories are usually considered as an important part of the curriculum [1]. They provide hands-on training and allow students to better understand the topics they are learning [2] as well as allow students to learn important skills for their future lives [3]. Much research has gone into the topic of what learning outcomes should be provided by laboratories [4], [5].

One can argue that computer science is a special case in terms of STEM education. If we look at the historic development of the discipline according to Tedre and Sutinen [6], the computing discipline is based on three traditions: the mathematical tradition (based on theoretical structures and formal proofs), the scientific tradition (studying information processes which can be found naturally and artificially) and the engineering tradition (constructing computing artefacts e.g. through electrical engineering). Coy [7] named three disciplines of American universities: Computer Engineering (based on electrical / electronical engineering), Computer Science (based on applied mathematics) and Information Science (based on technological science). In addition, Coy [7] describes the German word *Informatik*, which can not directly be translated to any of the American disciplines. Denning [8] divides *computing* into *Mechanics* (structure and operation of computation), *Design* (use the mechanics to build abstract objects) and *Computing Practices* (construct systems for users). **For the remainder of this work, the term 'computer science' is used to describe all areas mentioned in this paragraph.** This allows us to take a view over the whole discipline of computer science, even if we loose a clear definition of what computer science actually is.

No matter which definition or context of computer science we use, computer science is a field of study that can not easily be grasped or compared to more traditional fields of studies like chemistry or biology. In addition, some properties one might expect from a laboratory like a physical room [9] do not necessarily make sense for all computer science disciplines (e.g. programming can be done at a normal computer). This brings up the question: What exactly is a laboratory in computer science? For this study, we want to define a laboratory in the sense of an ostensive definition [10]: Instead of giving a lexical definition, a number of computer science laboratories are viewed (and aggregated). That way, it is possible to get an understanding of what is currently understood as a computer science laboratory.

To answer that question, this work focusses on three aspects to get an understanding of computer science laboratories:

Q1: In what contexts are laboratories used in computer science?
Q2: If used in teaching: What didactical concepts are used?
Q3: What disciplines are represented as a laboratory?

II. Method: Literature Review

To find an answer to the three aspects **Q1** to **Q3**, a literature review was performed. To get a good impression of what is understood as a laboratory in computer science, the digital libraries of the IEEE[1] and the ACM[2] were used for retrieving papers. All papers are from the last five years, i.e. they were published between 2017 and 2021.

Two search terms were chosen for this literature research: **Laboratory** and **Computer Science**. However, searching for them everywhere in the document posed a problem: In many cases, a laboratory was mentioned in the authors' bio and nowhere else. Such a paper would not be included into the

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[1]IEEE Xplore - https://ieeexplore.ieee.org/
[2]ACM Digital Library - https://dl.acm.org/

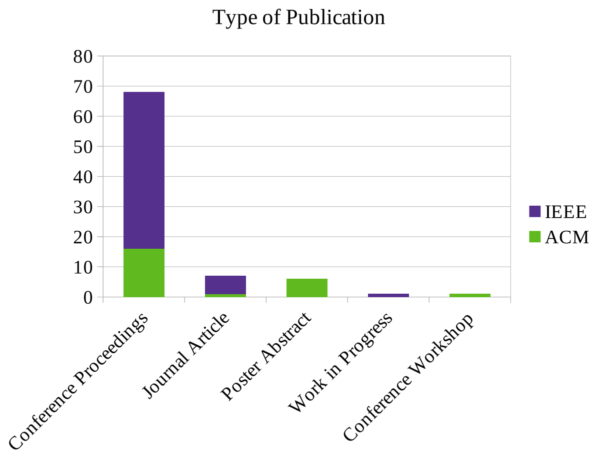

Fig. 1. Type of publication of all included papers ($n = 83$).

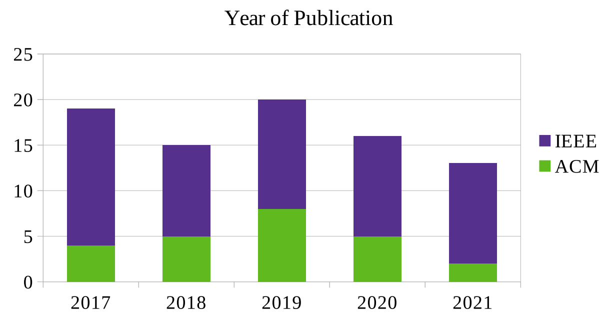

Fig. 2. Year of publication of all included papers ($n = 83$).

literature research due to the inclusion criterion I1 not being fullfilled (see below). To counter this, both search terms had to appear in the abstract (which reduces the total number of papers found and thus might exclude some relevant papers in this literature review).

To be included into this literature research, a paper must fulfil all of the following inclusion criteria:

I1: The paper describes at least some details of a laboratory. A simple mention of a laboratory with no details is not enough.
I2: The paper is written in English.

In addition, it must fulfil none of the following exclusion criteria.

E1: The paper is not available online as full-text.
E2: The paper is not about computer science (or is interdisciplinary and no computer science is included).

The search on the digital libraries as well as the download of all papers were performed on 20$^{\text{th}}$ of July 2022. A total of 163 papers were downloaded (IEEE: 120, ACM: 43). After eliminating duplicates (1 paper) and applying inclusion and exclusion criteria, a total of 83 (IEEE: 59, ACM: 24) papers were included in the literature research. The type of publication of all included papers can be seen in Fig. 1 (mostly

TABLE I
PUBLICATION VENUE OF ANALYSED PAPERS. VENUES WITH ONLY ONE PAPER INCLUDED IN THE REVIEW ARE COMBINED TO A SINGLE CATEGORY BASED ON DIGITAL LIBRARY

Venue	**Number**
ACM Journal of Computing Sciences in Colleges	9
IEEE Global Engineering Education Conference (EDUCON)	8
ACM Technical Symposium on Computer Science Education	7
IEEE Frontiers in Education Conference (FIE)	5
IEEE International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)	5
IEEE International Conference on Computer Systems, Electronics and Control (ICCSE)	3
ACM Conference on Innovation and Technology in Computer Science Education (ItiCSE)	2
ACM other venues	*6*
IEEE other venues	*38*

conference proceedings) and the year in Fig. 2 (around the same number for each year). In addition, the venues of the publication can be found in Tab. I. Please note that the majority of papers reviewed belonged to a venue where only one paper was included in this literature review.

To answer the three research questions Q1-Q3, all papers were inductively categorised. Each paper can be added to multiple categories but is only counted once for each single category.

III. Q1: IN WHAT CONTEXTS ARE LABORATORIES USED IN COMPUTER SCIENCE?

To answer the first research question, all papers were categorised by the context of the laboratory described in the paper. The detailed results can be seen in Fig. 3. The following contexts were identified for laboratories in computer science:

- **mentioned in course**: The laboratory is mentioned in the context of course development, but no focus has been put on describing the laboratory.
- **course development**: The laboratory is described in the development of a (new) course.
- **curriculum development**: The laboratory is described in larger curriculum development, e.g in multiple courses that are not directly related.
- **laboratory technology (education/non-education)**: The technology used for building a laboratory is described in detail. It is important to note that all described laboratories are used in education, with two [84], [86] also designed for general research.
- **educational research / laboratory pedagogy research**: The laboratory is used for educational research / laboratory pedagogy research.
- **learning analytics research**: The laboratory is used for learning analytics research.
- **general university development**: Laboratories are discussed in the context of the whole university instead of specific courses.

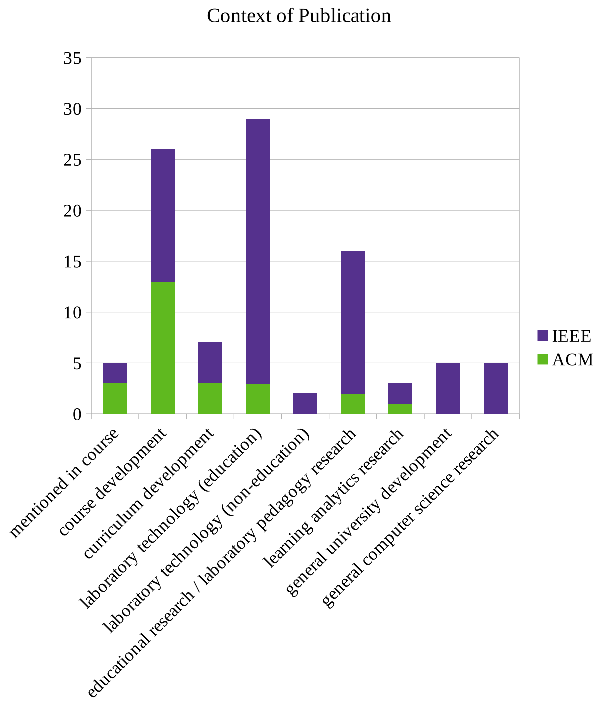

Fig. 3. Context in which the laboratory is described.

- **general computer science research**: The laboratory is not used for education but instead for general computer science research.

In general, most laboratories are described in a teaching context. To be more specific, two major categories can be seen: *course development* as well as broader teaching research (containing *laboratory technology* as well as *educational research / laboratory pedagogy research*).

There are three factors which might introduce some bias to the results:

1) It is possible that these results are influenced by the decision of forcing all search terms to appear in the abstract. However, it is hard to estimate in which direction this bias might be.
2) Researchers, especially in didactics and pedagogy, have a high motivation of publishing the laboratory they built. In contrast, researchers working in laboratories do might not have a high motivation, while some companies might even forbid publishing exact details about their laboratory. Therefore, it can be assumed that a bias towards teaching laboratories exists in scientific literature.
3) It can be assumed that research papers in computer science do not describe the laboratory of their experiments in detail but instead focus on the experiment and the outcome. This would further screw the distribution towards labotatories in a teaching context.

IV. Q2: If used in teaching: What didactical concepts are used?

The target of this question is to understand how the creators of a laboratory understand the didactical concepts they use. Because of this, no further interpretation of the concepts described in the reviewed paper was done (with the exception of learning objectives and learning outcomes). This might lead to more and finer categories, but better describes the current status of computer science laboratories as understood in literature. A statement like *'Furthermore, a complete didactical concept was developed to integrate this platform into teaching and learning of Computer Science in engineering courses at our university of Applied Sciences.'* [66, p. 478] without more context is interpreted as no didactical concept, since a reader can not extract any useful information from it. The found didactical concepts are (see Fig. 4 for distribution):

- no didactical concept mentioned
- not used for teaching, e.g. research laboratory
- learning objectives (knowledge) [11]
- learning outcomes [11]
- APOS theory [12]
- work-related learning [13]
- game-based learning [14]
- gamification [15]
- evidence-based education [16]
- team-based learning [17]
- constructivist education / learning theory [18]
- experiential learning theory [19]
- problem-based learning [20]
- personalized learning [21]
- Bloom's taxonomy [22]
- active learning [23]
- social constructivism learning [24]
- peer-led team learning [25]
- blended learning [26]
- competency model [27]
- flipped classroom [28]
- students attentiveness [29]
- learning styles / learning types [30]
- just-in-time teaching [31]
- learning-by-doing [32]
- computer supported collaborative learning [33]
- online collaborative learning [34]
- project-oriented learning [20]
- Merrill's first principles [35]
- Gagne's 9 events of instruction [36]

The first thing to note is the high number of papers not including any didactical concept. The number of papers without a didactical concept amounts to 37 papers (IEEE: 29, ACM: 8) or 48% of all laboratories described as being used for teaching. Based on this, the conclusion could be drawn that didactical is often neglected in learning laboratory design.

In addition, many different didactical concepts are used in the reviewed papers. Even if it would be possible to combine some of the categories, there would still be a large number

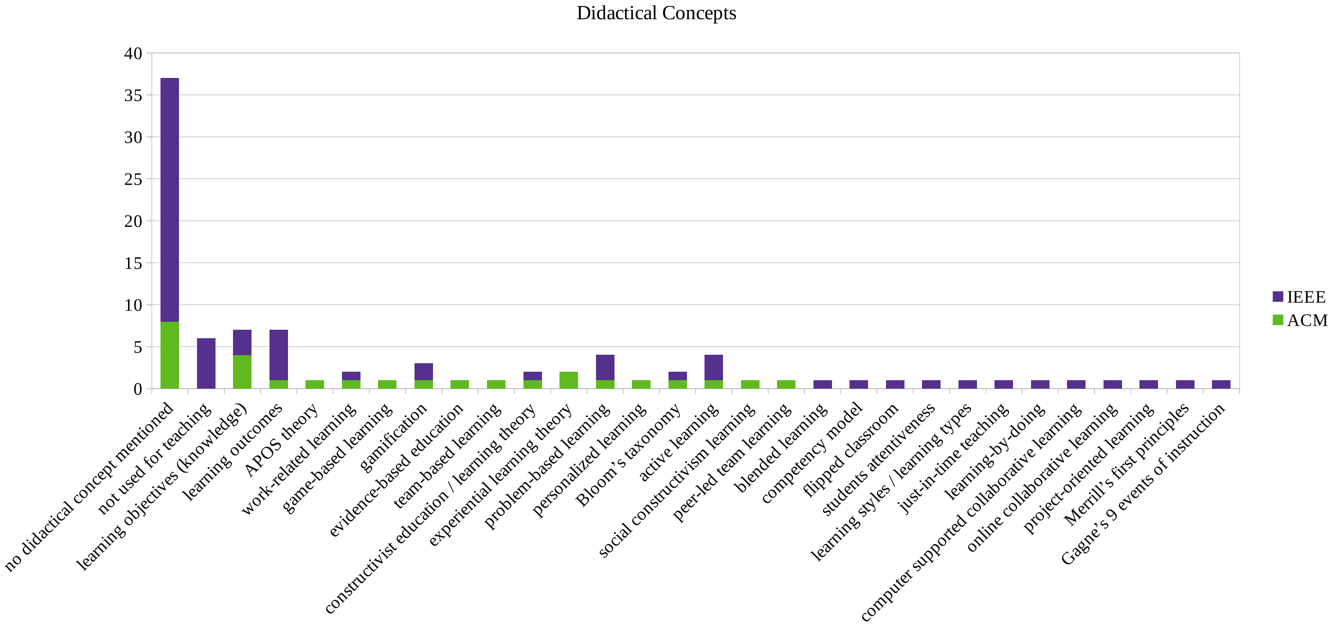

Fig. 4. Didactical concepts in which the laboratory is described. The didactical concepts are taken from the reviewed papers without further interpretation.

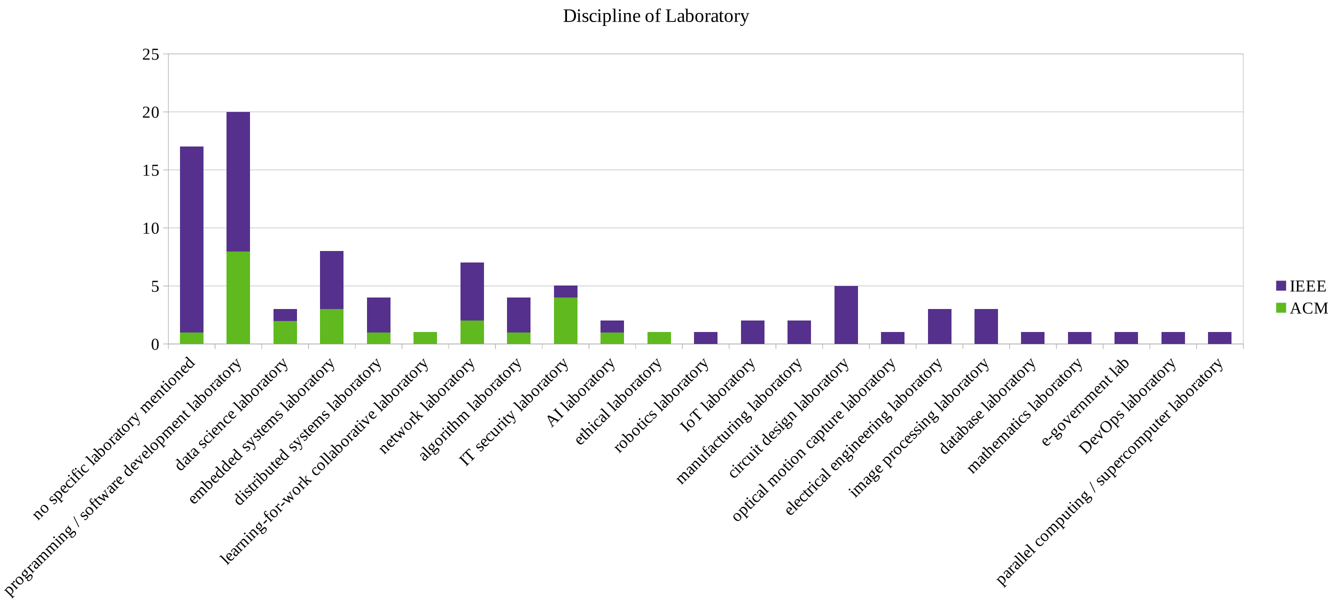

Fig. 5. Discipline in which the laboratory is described.

of didactical concepts remaining. This makes laboratories not only hard to compare, but also makes it hard for people who want to develop new laboratories to choose the right didactical concept. It would be useful for future research to develop a more unified didactical concept model for laboratories in computer science.

V. Q3: What disciplines are represented as a laboratory?

The last research question asks which disciplines can be found in computer science laboratories. To get an accurate understanding, categories were taken from literature as reported with only minimal interpretation even if it leads to more and finer categories (same as in the last Section). The following disciplines were found in the literature review (see Fig. 5 for a detailed overview):

- no specific laboratory mentioned
- programming / software development laboratory
- data science laboratory
- embedded systems laboratory
- distributed systems laboratory
- learning-for-work collaborative laboratory
- network laboratory
- algorithm laboratory
- IT security laboratory
- AI laboratory
- ethical laboratory
- robotics laboratory
- IoT laboratory
- manufacturing laboratory
- circuit design laboratory
- optical motion capture laboratory
- electrical engineering laboratory
- image processing laboratory
- database laboratory
- mathematics laboratory
- e-government lab
- DevOps laboratory
- parallel computing / supercomputer laboratory

The largest group of papers (IEEE: 12, ACM: 8) is about *programming / software development laboratory*, which amounts to about 21% of all laboratories. This is not surprising since programming and software development can be considered as an important part of computer science education [37], [38]. A similar number of papers (IEEE: 16, ACM: 1), about 18%, do not have a specific laboratory description in them.

However, laboratories exist for a wide range of disciplines within computer science. These also include more niche disciplines like *e-government lab* [98] and topics more leaning to other fields of study like *ethical laboratories* [62] or *mathematics laboratories* [96]. In total, it can be said that laboratories are developed for a diverse set of disciplines and it is likely that for every discipline in computer science laboratories can be developed.

VI. Conclusion: What exactly is a laboratory in computer science?

Now that the research questions Q1-Q3 are answered, the overall question of what a laboratory in computer science (as described in recent literature) is can be answered, too.

Based on Q1, we can say that a typical laboratory in computer science is described in the context of teaching, although teaching here also encompasses topics like *laboratory technology* and *educational research / laboratory pedagogy research*. These laboratories are deployed in a wide range of different disciplines (Q3). This can be seen as positive since laboratories in general improve learning [2] and this study shows that they can be used in probably every discipline.

One problem this study revealed is the lack of didactical concepts used in computer science laboratories (Q2). Almost half of the papers for teaching laboratories do not describe any didactical concepts. This is not a desirable situation, since without proper didactical concepts the design of laboratories might not suitable for teaching and it might be hard to evaluate the effectiveness of those laboratories. In addition, the concepts described by the reviewed papers with a didactical concept cover a wide range of principles. Here, a unification of didactical concepts would be useful to make laboratories more comparable.

VII. Suggestions for Future Research

Based on the literature review, I would suggest the following improvements for future research on computer science laboratories:

1) Future research should not only describe laboratories for teaching, but also interesting laboratories for research. Some laboratories for research (e.g. [109]) and combined research / teaching (e.g. [84]) are described. However, this can be extended on.
2) Future development of laboratories should focus on a 'didactical concepts first' approach. If laboratories are built without a didactical concept behind them, they might not be effective for teaching. Therefore, building laboratories with a didactical concept will ensure the teaching quality in those laboratories.
3) It would be helpful to focus on a few didactical concepts instead of having a wide variety of those. That way, laboratories would be more comparable and it might be easier to transfer fitting parts from one laboratory to another.
4) For further developed laboratories for teaching, learning outcomes for laboratories as described in [4], [5] should be taken into consideration.

References

[1] D. Satterthwait, "Why are 'hands-on' science activities so effective for student learning?" *Teaching Science*, vol. 56, no. 2, pp. 7–10, 2010. [Online]. Available: https://search.informit.org/doi/10.3316/aeipt.182048

[2] F. L. Forcino, "The importance of a laboratory section on student learning outcomes in a university introductory earth science course," *Journal of Geoscience Education*, vol. 61, no. 2, pp. 213–221, 2013. [Online]. Available: https://doi.org/10.5408/12-412.1

[3] N. S. Edward, "The Role of Laboratory Work in Engineering Education: Student and Staff Perceptions," *The International Journal of Electrical Engineering & Education*, vol. 39, no. 1, pp. 11–19, 2002. [Online]. Available: http://journals.sagepub.com/doi/10.7227/IJEEE.39.1.2

[4] L. D. Feisel and A. J. Rosa, "The role of the laboratory in undergraduate engineering education," *Journal of Engineering Education*, vol. 94, no. 1, pp. 121–130, 2005. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/j.2168-9830.2005.tb00833.x

[5] M. Soll and K. Boettcher, "Expected learning outcomes by industry for laboratories at universities," in *IEEE German Education Conference 2022*, Berlin, 2022, in press.

[6] M. Tedre and E. Sutinen, "Three traditions of computing: what educators should know," *Computer Science Education*, vol. 18, no. 3, pp. 153–170, 2008. [Online]. Available: https://doi.org/10.1080/08993400802332332

[7] W. Coy, *Was ist Informatik?* Berlin, Heidelberg: Springer Berlin Heidelberg, 2001, pp. 1–22. [Online]. Available: https://doi.org/10.1007/978-3-642-56774-2_1

[8] P. J. Denning, "Great principles of computing," *Commun. ACM*, vol. 46, no. 11, pp. 15–20, 2003. [Online]. Available: https://doi.org/10.1145/948383.948400

[9] J. Berendes and M. Gutmann, "Wozu labor? zur vernachlässigten erkenntnistheorie hinter der labordidaktik," in *Labore in der Hochschullehre: Labordidaktik, Digitalisierung, Organisation*, T. Claudius, D. May, S. Frye, T. Haertel, T. R. Ortelt, S. Heix, and K. Lensing, Eds. wbv Publikation, 2020, pp. 35–49.

[10] C. H. Whiteley, "Meaning and ostensive definition," *Mind*, vol. 65, no. 259, pp. 332–335, 1956. [Online]. Available: http://www.jstor.org/stable/2251515

[11] D. Kennedy, *Writing and using learning outcomes: a practical guide*. University College Cork, 2006.

[12] E. Dubinsky and M. A. Mcdonald, *APOS: A Constructivist Theory of Learning in Undergraduate Mathematics Education Research*. Dordrecht: Springer Netherlands, 2001, pp. 275–282. [Online]. Available: https://doi.org/10.1007/0-306-47231-7_25

[13] J. M. Dirkx, "Work-related learning in the united states: Past practices, paradigm shifts, and policies of partnerships," in *The SAGE Handbook of Workplace Learning*. SAGE Publications Ltd, 2011, pp. 293–306.

[14] M. Prensky, "Digital game-based learning," *Comput. Entertain.*, vol. 1, no. 1, p. 21, 2003. [Online]. Available: https://doi.org/10.1145/950566.950596

[15] K. M. Kapp, *The gamification of learning and instruction: game-based methods and strategies for training and education.* John Wiley & Sons, Inc., 2012.

[16] P. Davies, "What is evidence-based education?" *British Journal of Educational Studies*, vol. 47, no. 2, pp. 108–121, 1999. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1111/1467-8527.00106

[17] K. K. McMahon, *Team-Based Learning*. Dordrecht: Springer Netherlands, 2010, pp. 55–64. [Online]. Available: https://doi.org/10.1007/978-90-481-3641-4_5

[18] R. J. Amineh and H. D. Asl, "Review of constructivism and social constructivism," *Journal of Social Sciences, Literature and Languages*, vol. 1, no. 1, pp. 9–16, 2015.

[19] D. Kolb, *Experiential learning: experience as the source of learning and development*. Englewood Cliffs, NJ: Prentice Hall, 1984. [Online]. Available: http://www.learningfromexperience.com/images/uploads/process-of-experiential-learning.pdf(dateofdownload:31.05.2006)

[20] J. E. Mills and D. F. Treagust, "Engineering education—is problem-based or project-based learning the answer?" *Australasian Journal Of Engineering Education*, no. 04, pp. 2–16, 2003.

[21] J. F. Pane, E. D. Steiner, M. D. Baird, and L. S. Hamilton, *Continued Progress: Promising Evidence on Personalized Learning*. Santa Monica, CA: RAND Corporation, 2015.

[22] D. R. Krathwohl, "A revision of bloom's taxonomy: An overview," *Theory Into Practice*, vol. 41, no. 4, pp. 212–218, 2002. [Online]. Available: https://doi.org/10.1207/s15430421tip4104_2

[23] C. C. Bonwell and J. A. Eison, "Active learning: Creating excitement in the classroom. 1991 ashe-eric higher education reports." *ASHE-ERIC Higher Education Report*, vol. 1, 1991.

[24] A. S. Palincsar, "Social constructivist perspectives on teaching and learning," *Annual Review of Psychology*, vol. 49, no. 1, pp. 345–375, 1998, pMID: 15012472. [Online]. Available: https://doi.org/10.1146/annurev.psych.49.1.345

[25] S. Horwitz, S. H. Rodger, M. Biggers, D. Binkley, C. K. Frantz, D. Gundermann, S. Hambrusch, S. Huss-Lederman, E. Munson, B. Ryder, and M. Sweat, "Using peer-led team learning to increase participation and success of under-represented groups in introductory computer science," *SIGCSE Bull.*, vol. 41, no. 1, pp. 163–167, 2009. [Online]. Available: https://doi.org/10.1145/1539024.1508925

[26] N. Friesen, "Report: Defining blended learnin," 2012.

[27] D. Rodriguez, R. Patel, A. Bright, D. Gregory, and M. K. Gowing, "Developing competency models to promote integrated human resource practices," *Human Resource Management*, vol. 41, no. 3, pp. 309–324, 2002. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/hrm.10043

[28] G. Akçayır and M. Akçayır, "The flipped classroom: A review of its advantages and challenges," *Computers & Education*, vol. 126, pp. 334–345, 2018. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0360131518302045

[29] D. M. Bunce, E. A. Flens, and K. Y. Neiles, "How long can students pay attention in class? a study of student attention decline using clickers," *Journal of Chemical Education*, vol. 87, no. 12, pp. 1438–1443, 2010. [Online]. Available: https://doi.org/10.1021/ed100409p

[30] N. Othman and M. H. Amiruddin, "Different perspectives of learning styles from vark model," *Procedia - Social and Behavioral Sciences*, vol. 7, pp. 652–660, 2010, international Conference on Learner Diversity 2010. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1877042810020926

[31] G. M. Novak, E. T. Patterson, A. D. Gavrin, and W. Christian, "Just in time teaching," *American Journal of Physics*, vol. 67, no. 10, pp. 937–938, 1999. [Online]. Available: https://doi.org/10.1119/1.19159

[32] H. W. Reese, "The learning-by-doing principle," *Behavioral Development Bulletin*, vol. 17, no. 1, pp. 1–19, 2011.

[33] G. Stahl, T. Koschmann, and D. Suthers, *Computer-Supported Collaborative Learning*, 2nd ed., ser. Cambridge Handbooks in Psychology. Cambridge University Press, 2014, pp. 479–500.

[34] J. L. Moore, C. Dickson-Deane, and K. Galyen, "e-learning, online learning, and distance learning environments: Are they the same?" *The Internet and Higher Education*, vol. 14, no. 2, pp. 129–135, 2011, web mining and higher education: Introduction to the special issue. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1096751610000886

[35] M. D. Merrill, "First principles of instruction," *Educational Technology Research and Development*, vol. 50, no. 3, pp. 43–59, 2002. [Online]. Available: https://doi.org/10.1007/BF02505024

[36] R. M. Gagne and L. J. Briggs, *Principles of instructional design.* Oxford, England: Holt, Rinehart & Winston, 1974.

[37] T. Lethbridge, "What knowledge is important to a software professional?" *Computer*, vol. 33, no. 5, pp. 44–50, 2000.

[38] A. Robins, J. Rountree, and N. Rountree, "Learning and teaching programming: A review and discussion," *Computer Science Education*, vol. 13, no. 2, pp. 137–172, 2003. [Online]. Available: https://doi.org/10.1076/csed.13.2.137.14200

ACM Papers Included in Literature Research

[39] Y. Kortsarts, K. Akhuseyinoglu, J. Barria-Pineda, and P. Brusilovsky, "Integrating personalized online practice into an introductory programming course," *Journal of Computing Sciences in Colleges*, vol. 35, no. 8, pp. 264–266, 2020.

[40] S. Kim, "Project-based data science course design," *Journal of Computing Sciences in Colleges*, vol. 37, no. 3, pp. 22–35, 2021.

[41] M. G. Terwilliger, J. L. Jackson, C. L. Stenger, and J. A. Jerkins, "Using computer programming activities and robots to teach generalization of a geometry concept," *Journal of Computing Sciences in Colleges*, vol. 34, no. 3, pp. 82–90, 2019.

[42] M. Black and C. H. Lee, "An embedded systems course for cross-disciplinary research," *Journal of Computing Sciences in Colleges*, vol. 34, no. 1, pp. 202–209, 2018.

[43] J. Herbst, "Using a systems perspective to teach introduction to machine organization with laboratory," *Journal of Computing Sciences in Colleges*, vol. 32, no. 6, pp. 189–191, 2017.

[44] N. Slamnik-Kriještorac, H. C. C. de Resende, and J. M. Marquez-Barja, "Practical teaching of distributed systems: A scalable environment for on-demand remote experimentation," in *Proceedings of the 6th EAI International Conference on Smart Objects and Technologies for Social Good*, ser. GoodTechs '20. New York, NY, USA: Association for Computing Machinery, 2020, pp. 120–125. [Online]. Available: https://doi.org/10.1145/3411170.3411230

[45] T. Vardanega and M. Fedeli, "A two-staged capstone project to foster university-business dialogue," in *Proceedings of the 23rd Annual ACM Conference on Innovation and Technology in Computer Science Education*, ser. ITiCSE 2018. New York, NY, USA: Association for Computing Machinery, 2018, pp. 272–277. [Online]. Available: https://doi.org/10.1145/3197091.3197130

[46] R. Kadel, S. J. Halder, K. Paudel, and M. P. Gurung, "Analyzing effect of gbl on student engagement and academic performance in computer networking course," in *Proceedings of the 20th International Conference on Information Integration and Web-Based Applications & Services*, ser. iiWAS2018. New York, NY, USA: Association for Computing Machinery, 2018, pp. 143–145. [Online]. Available: https://doi.org/10.1145/3282373.3282855

[47] I. Russell, Z. Duan, and A. Jung, "Introducing data analytics concepts in a cs course for non-majors," in *Proceedings of the 2020 ACM Conference on Innovation and Technology in Computer Science Education*, ser. ITiCSE '20. New York, NY, USA: Association for Computing Machinery, 2020, p. 551. [Online]. Available: https://doi.org/10.1145/3341525.3393963

[48] M. Missiroli, D. Russo, and P. Ciancarini, "Agile for millennials: A comparative study," in *Proceedings of the 1st International Workshop on Software Engineering Curricula for Millennials*, ser. SECM '17. IEEE Press, 2017, pp. 47–53. [Online]. Available: https://doi.org/10.1109/SECM.2017.7

[49] I. Russell, C. P. Rosiene, and A. Gold, *A CS Course for Non-Majors Based on the Arduino Platform*. New York, NY, USA: Association for Computing Machinery, 2020, p. 1309. [Online]. Available: https://doi.org/10.1145/3328778.3372595

[50] A. F. Lobo and G. R. Baliga, "A project-based curriculum for algorithm design and np-completeness centered on the sudoku problem," *Journal of Computing Sciences in Colleges*, vol. 32, no. 3, pp. 110–118, 2017.

[51] S. Kentros, M. Wadhwa, L. Sreeramareddy, K. Kaur, M. Ebenfield, and A. Shwedel, "Course redesign to improve retention: Finding the optimal mix of instructional approaches," *Journal of Computing Sciences in Colleges*, vol. 34, no. 6, pp. 97–106, 2019.

[52] L. Angeli, J. J. J. Laconich, and M. Marchese, *A Constructivist Redesign of a Graduate-Level CS Course to Address Content Obsolescence and Student Motivation*. New York, NY, USA: Association for Computing Machinery, 2020, pp. 1255–1261. [Online]. Available: https://doi.org/10.1145/3328778.3366910

[53] J. B. Almeida, A. Cunha, N. Macedo, H. Pacheco, and J. Proença, "Teaching how to program using automated assessment and functional glossy games (experience report)," *Proceedings of the ACM on Programming Languages*, vol. 2, no. ICFP, 2018. [Online]. Available: https://doi.org/10.1145/3236777

[54] S. Mason, "Examining faculty perceptions and approaches to problem solving, reflective learning and social learning in a computing education program: An exploratory case study," in *Proceedings of the 20th Annual Conference on Information Technology Education*, ser. SIGITE '19. New York, NY, USA: Association for Computing Machinery, 2019, pp. 177–182. [Online]. Available: https://doi.org/10.1145/3349266.3351415

[55] D. Azcona, P. Arora, I.-H. Hsiao, and A. Smeaton, "User2code2vec: Embeddings for profiling students based on distributional representations of source code," in *Proceedings of the 9th International Conference on Learning Analytics & Knowledge*, ser. LAK19. New York, NY, USA: Association for Computing Machinery, 2019, pp. 86–95. [Online]. Available: https://doi.org/10.1145/3303772.3303813

[56] Y. Deng, D. Huang, and C.-J. Chung, "Thoth lab: A personalized learning framework for cs hands-on projects (abstract only)," in *Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education*, ser. SIGCSE '17. New York, NY, USA: Association for Computing Machinery, 2017, p. 706. [Online]. Available: https://doi.org/10.1145/3017680.3022442

[57] J.-F. Lalande, V. Viet Triem Tong, P. Graux, G. Hiet, W. Mazurczyk, H. Chaoui, and P. Berthomé, "Teaching android mobile security," in *Proceedings of the 50th ACM Technical Symposium on Computer Science Education*, ser. SIGCSE '19. New York, NY, USA: Association for Computing Machinery, 2019, pp. 232–238. [Online]. Available: https://doi.org/10.1145/3287324.3287406

[58] C. M. B. Turner and C. F. Turner, "Analyzing the impact of experiential pedagogy in teaching socio-cybersecurity: Cybersecurity across the curriculum," *Journal of Computing Sciences in Colleges*, vol. 34, no. 5, pp. 12–22, 2019.

[59] M. Ergezer, B. Kucharski, and A. Carpenter, "Curriculum design for a multidisciplinary embedded artificial intelligence course: (abstract only)," in *Proceedings of the 49th ACM Technical Symposium on Computer Science Education*, ser. SIGCSE '18. New York, NY, USA: Association for Computing Machinery, 2018, p. 1087. [Online]. Available: https://doi.org/10.1145/3159450.3162309

[60] X. Mountrouidou, "Cyberpaths," *Journal of Computing Sciences in Colleges*, vol. 34, no. 3, p. 16, 2019.

[61] R. Rybarczyk and L. Acheson, "Interactive peer-led code reviews in cs2 curricula," in *Proceedings of the 50th ACM Technical Symposium on Computer Science Education*, ser. SIGCSE '19. New York, NY, USA: Association for Computing Machinery, 2019, pp. 659–665. [Online]. Available: https://doi.org/10.1145/3287324.3287442

[62] B. B. Bullock, F. L. Nascimento, and S. A. Doore, "Computing ethics narratives: Teaching computing ethics and the impact of predictive algorithms," in *Proceedings of the 52nd ACM Technical Symposium on Computer Science Education*, ser. SIGCSE '21. New York, NY, USA: Association for Computing Machinery, 2021, pp. 1020–1026. [Online]. Available: https://doi.org/10.1145/3408877.3432468

IEEE Papers Included in Literature Research

[63] S. Zong, "Construction of specialized laboratory of information and computing science based on big data mining technology," in *2021 2nd International Conference on Information Science and Education (ICISE-IE)*, 2021, pp. 961–964.

[64] P. Kumar and H. K. Rohil, "A novel framework for cloud computing enabled laboratory," in *2019 6th International Conference on Computing for Sustainable Global Development (INDIACom)*, 2019, pp. 854–861.

[65] N. Petrovic, V. Nejkovic, and M. Tosic, "Dealing with scalability of laboratory sessions in computer science university courses," in *2018 26th Telecommunications Forum (TELFOR)*, 2018, pp. 1–4.

[66] V. Haak, J. Abke, and K. Borgeest, "Conception of a lego mindstorms ev3 simulation for teaching c in computer science courses," in *2018 IEEE Global Engineering Education Conference (EDUCON)*, 2018, pp. 478–483.

[67] A. R. Rao and R. Dave, "Developing hands-on laboratory exercises for teaching stem students the internet-of-things, cloud computing and blockchain applications," in *2019 IEEE Integrated STEM Education Conference (ISEC)*, 2019, pp. 191–198.

[68] N. Ackovska and V. Kirandziska, "The importance of hands-on experiences in robotics courses," in *IEEE EUROCON 2017 -17th International Conference on Smart Technologies*, 2017, pp. 56–61.

[69] E. Blagodarny, A. Vedyakhin, and A. Raygorodsky, "Development of educational projects on the basis of technological platforms with artificial intelligence: The experience of mipt on the use of high vox-platform," in *2018 International Conference on Artificial Intelligence Applications and Innovations (IC-AIAI)*, 2018, pp. 12–17.

[70] A. Yaganteeswarudu and B. Devi, "The multi language audio compiler with video help," in *2018 3rd IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT)*, 2018, pp. 204–208.

[71] R. F. Maia, A. A. Massote, and F. Lima, "Innovative laboratory model based on partnerships and active learning," in *2017 IEEE Frontiers in Education Conference (FIE)*, 2017, pp. 1–5.

[72] H. Thorbergsson, K. S. Gudmundsson, K. Andersen, and S. Thorsteinsson, "Using fpgas in lab sessions," in *2017 27th EAEEIE Annual Conference (EAEEIE)*, 2017, pp. 1–4.

[73] A. D. Gueye, L. Yade, B. Gueye, O. Kasse, and C. Lishou, "Cloud and webrtc based laboratory solution for practical work in computer science for a traditional university," in *2020 IEEE Global Engineering Education Conference (EDUCON)*, 2020, pp. 1119–1124.

[74] M. S. d. S. Lopes, I. P. Gomes, R. M. P. Trindade, A. F. da Silva, and A. C. d. C. Lima, "Web environment for programming and control of a mobile robot in a remote laboratory," *IEEE Transactions on Learning Technologies*, vol. 10, no. 4, pp. 526–531, 2017.

[75] M. N. Kabiri and M. Wannous, “An experimental evaluation of a cloud-based virtual computer laboratory using openstack,” in *2017 6th IIAI International Congress on Advanced Applied Informatics (IIAI-AAI)*, 2017, pp. 667–672.

[76] N. Slamnik-Kriještorac, R. Van den Langenbergh, T. Huybrechts, S. M. Gutierrez, M. C. Gil, and J. M. Marquez-Barja, “Cloud-based virtual labs vs. low-cost physical labs: what engineering students think,” in *2021 IEEE Global Engineering Education Conference (EDUCON)*, 2021, pp. 637–644.

[77] J. Troya, J. A. Parejo, S. Segura, A. Gámez-Díaz, A. E. Márquez-Chamorro, and A. del Río-Ortega, “Flipping laboratory sessions in a computer science course: An experience report,” *IEEE Transactions on Education*, vol. 64, no. 2, pp. 139–146, 2021.

[78] M. Skublewska-Paszkowska and J. Smolka, “Enhancement of it student projects using 3d technology,” in *2017 IEEE Global Engineering Education Conference (EDUCON)*, 2017, pp. 204–207.

[79] M. Kotulla, M. Vrzala, and R. Gono, “Measuring of fault distance using the fault locator function of protection relay,” in *2019 20th International Scientific Conference on Electric Power Engineering (EPE)*, 2019, pp. 1–5.

[80] M. B. Firdaus, E. Budiman, J. A. Widians, N. M. Sinaga, S. Fadli, and F. Alameka, “Augmented reality for office and basic programming laboratory peripheral,” in *2018 2nd East Indonesia Conference on Computer and Information Technology (EIConCIT)*, 2018, pp. 41–45.

[81] I. Kaštelan, B. Pavković, M. Vranješ, M. Popović, and G. Velikić, “Modernizing laboratories for new courses in automotive software engineering,” in *2019 42nd International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, 2019, pp. 667–670.

[82] I. Kaštelan, B. Pavković, M. Vranješ, and M. Popović, “Modernized courses in automotive software engineering,” in *2020 43rd International Convention on Information, Communication and Electronic Technology (MIPRO)*, 2020, pp. 737–740.

[83] P. Yangyuen, A. Gongmanee, and N. Chaiarporn, “Impact of mobile application on student enguagement and public consciousness toward computer laboratory use,” in *2019 Joint International Conference on Digital Arts, Media and Technology with ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunications Engineering (ECTI DAMT-NCON)*, 2019, pp. 351–353.

[84] J. Xuebin, “Research on computer network virtual laboratory based on asp.net,” in *2017 International Conference on Computer Systems, Electronics and Control (ICCSEC)*, 2017, pp. 464–467.

[85] C. N. Corella, J. Noguez, E. José Martín Molina, E. Sotkoeva, and R. Salla, “Use of a decision-making laboratory to support student’s visual analysis for the solution of a transportation problem in mexico city,” in *2019 IEEE Frontiers in Education Conference (FIE)*, 2019, pp. 1–5.

[86] H. Liu, Z. Wang, L. Huang, and K. Wang, “Building a private cloud based on microservices for computer science laboratory in universities,” in *2020 7th International Conference on Information Science and Control Engineering (ICISCE)*, 2020, pp. 379–384.

[87] R. Simionov, S. Mollova, and R. Dolchinkov, “Integrated laboratory complex,” in *2020 43rd International Convention on Information, Communication and Electronic Technology (MIPRO)*, 2020, pp. 1567–1572.

[88] A. Amid, A. Ou, K. Asanović, Y. S. Shao, and B. Nikolić, “Vertically integrated computing labs using open-source hardware generators and cloud-hosted fpgas,” in *2021 IEEE International Symposium on Circuits and Systems (ISCAS)*, 2021, pp. 1–5.

[89] E. Tanuar, Y. Heryadi, Lukas, B. S. Abbas, and F. L. Gaol, “Using machine learning techniques to earlier predict student’s performance,” in *2018 Indonesian Association for Pattern Recognition International Conference (INAPR)*, 2018, pp. 85–89.

[90] Y. Sheng, H. Fan, L. Xiao, and J. Huang, “A virtual experiment platform based on openstack,” in *2017 12th International Conference on Computer Science and Education (ICCSE)*, 2017, pp. 744–749.

[91] K. Henke, H.-D. Wuttke, R. Hutschenreuter, and D. Streitferdt, “Interactive content objects as goldi-lab services : Interactive demonstration of icos within the hybrid online onlne lab goldi,” in *2019 5th Experiment International Conference (exp.at’19)*, 2019, pp. 229–230.

[92] S. Senthil Velan and V. R. Poluru, “Application of digital image processing techniques in determining the quality of arc and mig welding of steel joints,” in *2020 8th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO)*, 2020, pp. 1320–1325.

[93] O. T. S. Au, “Mini-lectures interleaved with exercises found beneficial in online learning,” in *2020 International Symposium on Educational Technology (ISET)*, 2020, pp. 138–141.

[94] M. Marín, Á. S. Places, C. Bonacic, and N. R. Brisaboa, “The transfer of technology in students’ curricula,” *IT Professional*, vol. 21, no. 5, pp. 6–10, 2019.

[95] M. Špoljarić, M. Hajba, and i. M. Pecimotika, “Interactive approach to digital logic,” in *2020 43rd International Convention on Information, Communication and Electronic Technology (MIPRO)*, 2020, pp. 1601–1606.

[96] A. Zakharov and Y. Zakharova, “The use of computer graphics in the study of the geometric modeling course,” in *2020 V International Conference on Information Technologies in Engineering Education (Inforino)*, 2020, pp. 1–5.

[97] A. Stojanova, N. Stojkovikj, M. Kocaleva, B. Zlatanovska, and C. Martinovska-Bande, “Application of vark learning model on “data structures and algorithms” course,” in *2017 IEEE Global Engineering Education Conference (EDUCON)*, 2017, pp. 613–620.

[98] M. A. H. Sutoyo, H. Priyambowo, A. Nurzahra, D. I. Sensuse, S. Al Hakim, and D. Satria, “Knowledge management system design using gamification: A case study of the e-government laboratory, universitas indonesia,” in *2019 International Conference on Computer, Information and Telecommunication Systems (CITS)*, 2019, pp. 1–5.

[99] A. Perez-Poch and D. López, “Just-in-time teaching improves engagement and academic results among students at risk of failure in computer science fundamentals,” in *2017 IEEE Frontiers in Education Conference (FIE)*, 2017, pp. 1–7.

[100] P. Seeling and J. Eickholt, “Levels of active learning in programming skill acquisition: From lecture to active learning rooms,” in *2017 IEEE Frontiers in Education Conference (FIE)*, 2017, pp. 1–5.

[101] D. Nair, “Online laboratory course using low tech supplies to introduce digital logic design concepts,” in *2021 International e-Engineering Education Services Conference (e-Engineering)*, 2021, pp. 121–126.

[102] D. Kitakoshi, K. Yanagisawa, and M. Suzuki, “Empirical study of student evaluations of research activity support system for higher education students in various fields,” in *2017 Conference on Technologies and Applications of Artificial Intelligence (TAAI)*, 2017, pp. 112–117.

[103] A. T S and R. M. R. Guddeti, “Unobtrusive students’ engagement analysis in computer science laboratory using deep learning techniques,” in *2018 IEEE 18th International Conference on Advanced Learning Technologies (ICALT)*, 2018, pp. 436–440.

[104] S. J. Lee, A. Jung, J. Park, and M. Yun, “Cost-efficient hands-on learning design for computer organization course,” in *2020 15th International Conference on Computer Science & Education (ICCSE)*, 2020, pp. 150–155.

[105] R. Gomez-Merchan, S. Vazquez, A. M. Alcaide, H. D. Tafti, J. I. Leon, J. Pou, C. A. Rojas, S. Kouro, and L. G. Franquelo, “Binary search based flexible power point tracking algorithm for photovoltaic systems,” *IEEE Transactions on Industrial Electronics*, vol. 68, no. 7, pp. 5909–5920, 2021.

[106] Q. Ding and S. Cao, “Rect: A cloud-based learning tool for graduate software engineering practice courses with remote tutor support,” *IEEE Access*, vol. 5, pp. 2262–2271, 2017.

[107] R. A. K. Jennings and G. Gannod, “Devops - preparing students for professional practice,” in *2019 IEEE Frontiers in Education Conference (FIE)*, 2019, pp. 1–5.

[108] G. Jourjon, J. M. Marquez-Barja, T. Rakotoarivelo, A. Mikroyannidis, K. Lampropoulos, S. Denazis, C. Tranoris, D. Pareit, J. Domingue, L. A. Dasilva, and M. Ott, “Forge toolkit: Leveraging distributed systems in elearning platforms,” *IEEE Transactions on Emerging Topics in Computing*, vol. 5, no. 1, pp. 7–19, 2017.

[109] D. Schwung, J. N. Reimann, A. Schwung, and S. X. Ding, “Self learning in flexible manufacturing units: A reinforcement learning approach,” in *2018 International Conference on Intelligent Systems (IS)*, 2018, pp. 31–38.

[110] W.-Y. Hwang, M. Haregot, and C. Kongcharoen, “Web-based hybrid virtualization laboratory to facilitate network learning: Hvlab,” in *2017 2nd International Conference on Information Technology (INCIT)*, 2017, pp. 1–6.

[111] M. Vladoiu and Z. Constantinescu, “Learning during covid-19 pandemic: Online education community, based on discord,” in *2020*

19th RoEduNet Conference: Networking in Education and Research (RoEduNet), 2020, pp. 1–6.

[112] S. Mollova, M. Zhekov, A. Kostadinov, and P. Georgieva, "Laboratory model for research on computer cluster systems," in *2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, 2018, pp. 1388–1393.

[113] C.-Y. Chung and I.-H. Hsiao, "Computational thinking in augmented reality: An investigation of collaborative debugging practices," in *2020 6th International Conference of the Immersive Learning Research Network (iLRN)*, 2020, pp. 54–61.

[114] S. Thangavelu, V. Rao, C. K. Shyamala, and C. S. Velayutham, "Introductory programming using non-textual modalities - an empirical study on skill assessment using rainfall problem," in *2019 IEEE Global Engineering Education Conference (EDUCON)*, 2019, pp. 867–871.

[115] A. Seffah, M. A. Kuhail, and J. Negreiros, "It teaching labs: Innovations in a distance education era," in *2021 9th International Conference on Information and Education Technology (ICIET)*, 2021, pp. 215–221.

[116] D. Meyer, B. Bergande, and D. Seyser, "Yes we can: A low-cost approach to simulate real-world automotive platforms in systems engineering education for non-computer science majors," in *2018 IEEE Global Engineering Education Conference (EDUCON)*, 2018, pp. 1713–1722.

[117] J. Dizdarević and A. Jukan, "Engineering an iot-edge-cloud computing system architecture: Lessons learnt from an undergraduate lab course," in *2021 International Conference on Computer Communications and Networks (ICCCN)*, 2021, pp. 1–11.

[118] W. Wang and X. Liu, "Application of virtual simulation experiments for undergraduate networking teaching," in *2021 4th International Conference on Intelligent Autonomous Systems (ICoIAS)*, 2021, pp. 194–198.

[119] Z. Duan, I. Russell, and A. Jung, "Active learning strategies: A computing course for undergraduates," in *2021 16th International Conference on Computer Science & Education (ICCSE)*, 2021, pp. 301–306.

[120] F. G. Rocha, L. S. Souza, T. S. Silva, and G. Rodríguez, "Enhancing the student learning experience by adopting tdd and bdd in course projects," in *2021 IEEE Global Engineering Education Conference (EDUCON)*, 2021, pp. 1116–1125.

[121] M. Kumar, V. Choppella, S. Sunil, and S. Syed, "A learnable-by-design (lead) model for designing experiments for computer science labs," in *2019 IEEE Tenth International Conference on Technology for Education (T4E)*, 2019, pp. 222–229.