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Current trends and developments in the application of digital tools and implementation of environmental awareness and sustainability in PBL-based STEM education: a dual systematic literature review

Introduction

Problem-Based Learning (PBL) is a part of meaningful, experiential learning, where students learn by solving problems and reflecting on their experiences (Barrows and Tamblyn, 1980). PBL can be used to help students become active learners by shifting learning to real-world problems and making students responsible for their learning. It places a dual emphasis on helping students develop strategies and construct knowledge (Collins et al., 1989; Hmelo and Ferrari, 1997; Kolodner et al., 1996). Cooperative learning methods are often used in problem-based learning (Hmelo-Silver, 2004).

STEM (Science Technology Engineering and Mathematics) in education is both a curriculum and a pedagogy. Moore et al. (2014) designated a framework that includes six important tenets for quality STEM education:
- the inclusion of math and science content,
- student-centered pedagogy,
- lessons are situated in an engaging and motivating context,
- inclusion of engineering design or redesign challenge,
- students learn from making mistakes,
- teamwork is emphasized.

However, Honey et al. (2014) argue that STEM education is not a well-defined concept.

The problem-based approach has been widely used in STEM education in recent years. PBL directly affected interest in a future STEM career (LaForce et al., 2017). PBL-STEM significantly increased students' problem-solving skills compared to the traditional class (Parno et al., 2019). Moreover, it was also found that STEM PBLs in schools helped lower-achieving students more and reduced achievement gaps (Han et al., 2015).

The combination of advances in technology, the digital literacy of Generation Z students, and online education due to the Covid-19 pandemic has meant that PbL STEM has very often been delivered in a digital environment in the recent past. For this reason, we considered it essential to examine how digitally-enhanced PBL in STEM education has been implemented in the last two years (from 2020 to 2022).

The most recent trends in the development of STEM curricula are implementing new, relevant topics, including environmental awareness (Nantsou and Tombras, 2022) and sustainability (Smith and Watson, 2019). Since these topics involve many fields of knowledge (Clark and Button, 2011), complex learning outcomes can be set and pursued (Rogers et al., 2015) – all the necessary vital competencies must be improved accordingly to critical thinking (Erikson and Erikson, 2019).

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Methodology

Research questions

Many recent publications which feature research on PBL-based STEM teaching and curricular development contain curricular elements and components of environmental education and sustainability. Therefore, we intended to analyze, classification, and assess the practical methods and tools along with the following criteria:

- **RQ1**: What methods and tools are used in problem-based STEM education that can raise environmental awareness and form the students' attitude concerning sustainability?
- **RQ2:** What key factors can we identify in successfully implementing such curricular content?
- **RQ3**: What types of digital devices are used in problem-based STEM education? What exactly is the role of digital tools in problem-based STEM learning?
- **RQ4**: What problems do students have to solve in problem-based STEM learning using a digital device?

Literature search process

We chose the Web of Science (WoS) database as it is the gateway for all the Science Citation Indexed (SCI) and Social Science Citation Indexed (SSCI) journals. We queried the WoS database for the first time on the 1st of April 2022. The search string (*problem-based learning AND STEM)* was keyed into the advanced search option of the Web of Science database. We then specified the range of years from 2020 to 2022. Problem-based learning and STEM research areas have been very active over the years. However, we investigate only the most recent literature because technology evolves and rapidly changes. We, therefore, focused our research on considering studies from 2020 to 2022.

Eligibility criteria

Inclusion and exclusion criteria were set to refine further the 377 results obtained. First, we read the 377 abstracts. We then looked at how these articles were grouped around broad themes. We found two particular groups:

- PBL in STEM education by using some digital device,
- PBL is related to environmental education or sustainability in STEM education.

Afterward, we narrowed our list to only articles on topics 1 or 2 above (126 articles). Of the studies with topics mentioned above, only the following were considered:

PBL in STEM education by using some kind of digital device

Of the studies with topics mentioned above, only the following were considered:

- Inclusion criteria: (a) empirical studies, (b) PBL in STEM education must be the central topic of the article, and (c) the study must focus on students and their PBL activities in STEM education.
- Exclusion criteria: (a) inadequate genre (theoretical study, literature, or systematic literature review), (b) the teachers are the main actors of the study (instead of students), (c) the study focuses on the digital tool that can be used to implement PBL in STEM education, (d) non-English articles, (e) articles in which the full text was not available.

After this procedure, we got 14 articles about problem-based learning in STEM education using a digital device.

PBL related to environmental education or sustainability in STEM education

Out of the studies mentioned above, only the following ones were considered:

- Inclusion criteria: (a) empirical studies, (b) PBL in STEM education must be the main instrument to propagate environmental awareness towards the pupils, and (c) the study focuses at least partially on students and their PBL activities in STEM education.
- Exclusion criteria: (a) inadequate genre (theoretical study, literature, or systematic literature review), (b) non-English articles, and (c) articles in which the full text was not available.

After this procedure, we got 13 articles about problem-based learning in STEM education-related to either environmental education or sustainability. Out of the remaining articles, one was related to both of our chosen topics, so altogether, this article covers the systematic review of those 26 articles (Fig. 1).

Figure 1: An overview of the search protocol
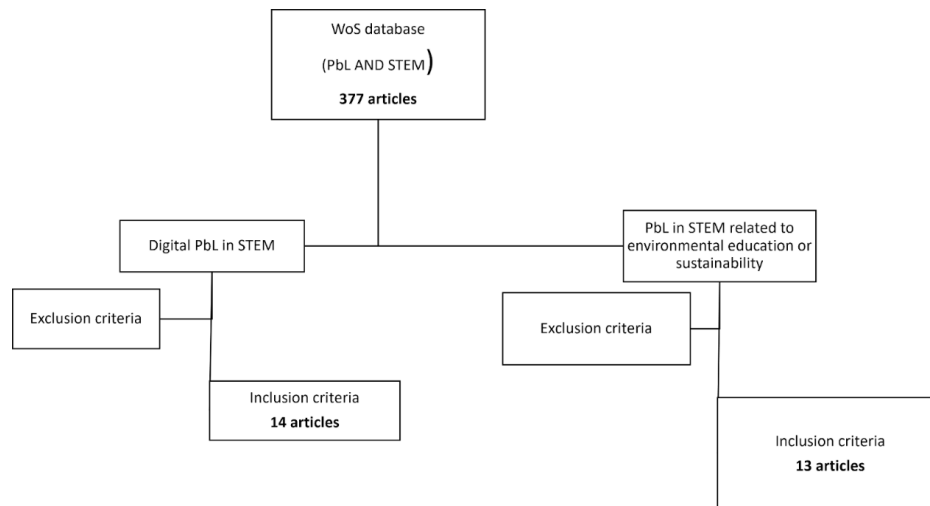
How PBL in STEM education contributes to environmental awareness and sustainability – and how it can be implemented successfully

General characteristics of RQ1

A minority (n=3) of the collected articles were based mainly on the development of a specific framework (Nawi et al., 2019) or model for (not necessarily only) environmental education, which put the focus of the entire learning process on the students, e.g., IGNITE (Dotson et al., 2020) or PRInK (Yahaya et al., 2021). However, since Nawi et al. tested their framework on a specific topic, we also classified their article as a case study. Therefore, this article and all the remaining publications (n=11) were specific case studies in which the application of certain problem-based and other learning tools and methods were used during the learning process. The subjects of the studies varied from 3rd-grade pupils to university students and pre-service teachers (Rico et al., 2021; Maass et al., 2022).

Educational methods for the frameworks

Since it is common practice to the couple (C)PBL and TEL (Technology-Enhanced Learning) (Nawi et al., 2019) or even its more advanced form of TEAL (Technology-Enabled Active Learning) (Shay et al., 2020), the most common component of these models was the technology as mentioned above *assisted learning* in many forms, especially Computer-Assisted Learning (Yahaya et al., 2021; Molan et al., 2022).

Other primary aspects were contextualizing the problem and the student's motivation. For this, the teachers and educators used the 5E (Engage, Explore, Explain, Elaborate, Evaluate) model (Bybee et al., 2006) for instruction in many cases (n=7).

Educational tools for the methods

As Table 1. shows, the educational tools used by the studies ranged from minor (Nawi et al., 2019) to no (Songer and Ibarrola Recalde, 2021; Talley et al., 2021) use of apps as a learning platform to partly (Rossano and Calvano, 2020) or immersive virtual environments (Molan et al., 2022).

The case studies can be divided into three categories based on the level of digitalization their methods and tools used based on the SAMR model (Hamilton et al., 2016):

- In some cases, there is no need to use technology further than to substitute or augment the already existing research and education tools to make the learning tools and the process more compatible with the younger generations (Maass et al., 2022; Rico et al., 2021; Songer and Ibarrola Recalde, 2021; Snell-Rood et al., 2021). It also makes research and education activities more easily conductive for technologically less developed institutions and communities (Gallay et al., 2021; 2021; Talley et al., 2021).

- In the remaining cases, digital technology can modify or even wholly redefine certain parts of the learning process by providing a new feature (Araya and Collanqui, 2021; Nawi et al., 2019; Shay et al., 2021) or a completely new task (Molan et al., 2021; Rossano and Calvano, 2020).

Table 1: Classification of the case studies by scientific topic, research subjects and main educational tool.

Article	Scientifis topic	Res. subjects	Ed. tool(s)
Araya and Collanqui, 2021	CO2 emission	cross-border 8th grade classes (Chile and Peru)	ConectaIdeas (cloud-based educational platform)
Gallay et al, 2021	social justice and STEM	6th to 12th grade students	problem based STEM projects
Maass et al, 2022	active citizenship	pre-service teachers in six European countries	problem-based porf. developm. (PD) courses
Molan et al, 2021	bushfire safety	4th to 6th grade students	immersive virtual environment (IVE)
Nawi et al, 2019	low carbon awareness	8-9th grade students	technology-enhanced cooperative projects
Rico et al, 2021	sustainable development	pre-service teachers	PBL-oriented teacher-learning sequence (TLS)
Rossano and Calvano, 2020	ocean literacy, water pollution	4th grade students	educational video + computer game
Shay et al, 2020	carbon assimilation	racial/ethnic minority students in local communities	problem-based TEAL projects
Snell-Rood et al, 2021	COVID-19	summer schools students	PBL-oriented case study + lesson plan
Songer and Ibarrola R., 2021	solving socio-scientific issues via eco-solutioning	3rd to 6th grade students	complex tests
Talley et al, 2021	pollution in urban watersheds	local communities	data tracking, surveys, individual assessments and interviews

Education system
The first group of such features is those that can be regulated and monitored by levels and members of the education system or systems, which serve as a stage for innovation. One of the most important contributing factors is the clarity of all involved education policies – whether the policymakers (and the teachers) know and accept the goals of the modernization.

Those goals are usually clearly set in the learning outcomes, which can be categorized in many ways - e.g., by the types (content, practice) of learning items (Songer and Ibarrola Recalde, 2021) or by the classical three-way partitioning of the outcomes (stores of learning, capabilities, and attitudes). The latter was done implicitly in some articles (e.g., Rico et al., 2021) and more explicitly in others. For example, Molan et al. (2021) classify even more precise outcomes (learning objectives) for each step of the virtual PBL-based learning tool they designed - the most poignant examples of that are the three articles that involve different, precisely designed frameworks (Nawi et al., 2019) or models of learning (Dotson et al., 2020; Yahaya et al., 2021).

Another important systematic component of implementational success can be the instruments for development - however, the impact of these tools depends strongly on the complexity of the learning tools utilized by the learners. This impact can vary within vast limits, from having very little weight in the development (Maass et al., 2022) to being the sole instrument of the learning process (Rossano and Calvano, 2020).

A final addition to the potential contributing factors is a capable assessment system which may be created by developments of specific components of the internal assessment system of the school to support the means and goals of the modernization (Yahaya et al., 2021) and by creating and operating an independent, external assessment system to provide a risk-based evaluation (Nawi et al., 2019), or both (Dotson et al., 2020).

Role of the community (learners, teachers)
Other than formal education, some (n=3) studies introduced community science (Talley et al., 2021) or civic science (Gallay et al., 2021; Snell-Rood et al., 2021), especially so to compensate for the underrepresentation of participants in specific ethnic (Hispanic minorities in the State of California (Talley et al., 2021; Shay et al., 2020)) or socio-economic status (urban (Gallay et al., 2021) and foster students (Songer and Ibarrola Recalde, 2021)) status. The most probable general idea behind applying this approach was to elevate the socio-scientific status of these communities.

Horizontal cooperation (another operational system through which the teachers can access pedagogical consultation opportunities, professional support (e.g., literature), or horizontal network cooperation) also has to be considered a contributing factor. It may happen between schools in the exact count(r)y (Gallay et al., 2021; Songer and Ibarrola Recalde, 2021; Talley et al., 2021) or at the same level of education but in different countries (Araya and Collanqui, 2021) and also between different levels of research and education (Dotson et al., 2020). The latter can largely contribute to a broader range of applications as education methods and tools used in multiple systems have to be up to many different standards - a good practice that has been developed that way is the already referenced 5E model, which was incorporated in many of the studies researched by us (n=7).

Perhaps the most crucial contributing factor belongs to the teachers as individuals: their lesson planning practice has to enable said development processes; otherwise, the necessary learning tools cannot be adequately utilized. It is incredibly decisive when it comes to complex ICT tools (Molan et al., 2021; Shay et al., 2020), new or uncommon methods and practices (Molan et al., 2021; Rossano and Calvano, 2020) - especially new frameworks (Nawi et al., 2019) or learning models (Dotson et al., 2020; Yahaya et al., 2021).

Discussion of RQ1 and RQ2 via SWOT of the implementation of PBL
After identifying the key factors necessary for implementational success, we can also analyze other features of PBL that may motivate and navigate the schools and teachers during the implementation process. To do that, instead of subjecting PBL to SWOT, we subject the implementation process itself to the analysis. As *Table 2.* suggests, these possible strengths, weaknesses, opportunities, and threats concerning the implementation of PBL can be divided into features that can be managed or altered by either the institutes or the educators themselves (and in some rare cases, both).

Table 2: SWOT analysis for the implementation of PBL

Strengths	Weaknesses
By applying PBL in practice, the teachers become capable of • enhancing the activity of students and their self-regulated learning, • facilitating more cooperation and collaboration between the learners, • deepening the understanding of the topic by discussion, • providing realistic topics and real life environmental problems. Also the school curricula can meet the educational challenges of the 21st century: • Complex topics can have many evaluation aspects, thus making detailed and personalized evaluation possible. • Complex tasks may also activate many of the key competences simultaneously.	The teachers also have to take into account that • objective summative evaluation can be notoriously difficult if not impossible in some cases, • and that PBL-based learning can be extremely resource-consuming (time, tools, sources, management of the learning process). The schools also have to consider that • use of PBL is not a common practice in Hungary - both the literature and methodolgy need serious development, • which means serious horizontal cooperation (for the purposes of design and development) may have to be created and developed.
Opportunities	**Threats**
PBL itself can become and intensive developmental tool for schools and teachers concerning • soft skills, • metacognitive and • metaaffective functions.	The teachers • may not be able to regulate the learning process in its entirety, • may only be able to facilitate instead of regulating in some cases, which may result in the loss of intrinsic motivation of the students (which can temporarily or permanently stun the learning process) The schools and the tutoriates have to also consider that the application of • improper methods and • lesson designs may also decrease student motivation or create free riders.

Unsurprisingly, the SWOT of the implementation is very similar to the SWOT of PBL itself (Azaceta et al., 2018; Patrick et al., 2020). however, the focus on specific areas is shifted towards the systematic

and human resources rather than the characteristics of the theoretical framework of (Collaborative) Problem Based Learning.

Problem-based learning in STEM education by using some kind of digital device

General characteristics of RQ3 (the types and role of digital devices)

Two large groups of digital devices appear in the studies examined. First, robotics was most popular - it was used in half of the cases (n=7). Different kinds of programming were used in problem-based STEM education in three cases. In the remaining four studies, virtual reality, computer games, computer agents, and interactive online boards occurred only once. The summary of these results is shown in *Table 3.*

Table 3: The types of digital devices used in problem-based STEM education

Categories	Sub-categories	More information	Articles
Robotics	detectors and sensors communicate with computer	Raspberry Pi	Major et al, 2021
	board microcontrollers	Arduino	Cui et al, 2021 Wang et al, 2021
		Micro:bit	Shahin et al, 2021
	robots capable of movement	sensitive robotic arm, a two-finger parallel gripper	Wang et al, 2021
		sumo robot	Sisman et al, 2022
		aerial drone	Bhuyan et al, 2020
		programmable robot ball (Sphero SPRK+)	Kim et al, 2021
Programming	text-based	Python language	Lin, YT et al, 2020
	block-based	Scratch	Weng et al, 2022 Century et al, 2020
Virtual reality (VR)			Dayarathna et al, 2020
Computer agent			Lin, KY et al, 2020
Computer game			Juric et al, 2021
Interactive online whiteboard			Ng et al, 2020

It should be made clear that, although programming is also used in robotics, in our study, programming means that the task is performed in a programming environment only, without using any physical panels, robots, sensors, or detectors.

Robotics in problem-based STEM education

Based on the studies reviewed, using robotics seems to provide an appropriate problem-based STEM learning environment for all ages. Robotic devices, like Arduino, Micro: bit, or Raspberry PI are based on more straightforward block-based programming; therefore, they are suitable for elementary or secondary school students (Weng et al., 2022; Cui et al., 2021) and beginners (Major et al., 2021; Wang et al., 2021). For high school students with programming backgrounds or university students, robotic tools based on a text-based programming language (like Python or C++) are more common. Robots supported by text programming exercises can do much more - for example, move their arms and grip something (Wang et al., 2021), play sumo (Sisman et al., 2022) or act as drones for reconnaissance (Bhuyan et al., 2020). Among the studies examined was only one in which a motion-capable device had to be coded using block-based programming (Kim et al., 2021).

Programming in problem-based STEM education

In our review of the articles, we found three cases where students had to solve a STEM problem in a programming environment (it is important to note that we are discussing non-robotics cases in this chapter). In two of three cases, it was used Scratch, a block-based programming tool that solves problems like saving money and fractal drawing among middle school students (Weng et al., 2022) or social and ecological problems among elementary school students (Century et al., 2020). Python, a text-based programming tool, was used among university students to solve scientific problems.

Other types of digital devices used in problem-based STEM education

Four other types of digital devices appeared in the articles reviewed. A computer game about operations with Roman numbers was used among elementary school students to detect students gifted in Mathematics (Juric et al., 2021).

A computer agent helped junior high school students with a web-based collaborative problem-solving system. A computer agent is a computer-simulated participant that can develop goals, perform tasks, communicate messages, respond to other participants' messages, react to the environment, adapt to changes in the environment, and learn concurrently (Lin, KY et al., 2020).

Active learning (via cooperative problem-based learning and peer assessment) was implemented using an interactive online whiteboard in a first-year calculus class (Ng et al., 2020).

An innovative virtual reality (VR) based approach was tried among engineering students to understand and simulate manufacturing concepts (Dayarathna, 2020).

Discussion on RQ3

Automated tools are the most popular digital devices for problem-based STEM learning. It could be because robotics makes the results of programming immediately visible. For example, the "robot arm" moves where students code it (Wang et al., 2021), and the aerial drone flies and takes pictures where they program it (Bhuyan et al., 2020). On the other hand, the fact that the physical device is not working well (or at all) is immediate feedback of lousy coding. Students' motivation in the world of mobile robots can be enhanced through gamification, as seen in the sumo robot championship (Sisman et al., 2022) or the robot ball competition (Kim et al., 2021).

Robotic devices based on block-based programming, which is much simpler than text-based programming, are also standard. These allow younger students (primary and secondary school) or beginners in programming to succeed in robotics. We could see an example of this in Hooke's Law experiment (Major et al., 2021), in collecting and processing sensor data for robotics electronics integration (Wang et al., 2021), in building a room capacity detector and a thermometer (Cui et al., 2021), or in such a real-world problem, like helping hospitals prioritize patients (Shahin et al., 2021).

However, there are some cases where we cannot use robotics. On the one hand, robotics tools are pretty expensive; on the other hand, if a course is only delivered online (Weng et al., 2022), it is more appropriate to use programming alone. For beginners and young students, block-based programming is the best - Scratch is the most popular of these, based on the articles studied (Century et al., 2020; Weng et al., 2022). Nevertheless, for example, complex scientific phenomena can also be modeled by programming - usually using text-based programming languages, like Python (Lin, YT et al., 2020).

We saw some further examples of the use of digital tools in problem-based STEM learning. For example, a VR-based approach can be used to understand and learn engineering concepts regardless of gender (Dayarathna, 2020). However, the authors argue that a new type of cheaper virtual reality technology is needed because of its high price.

Digital tools such as an interactive online whiteboard (Ng et al., 2020) and a computer agent (Lin, KY et al., 2020) can significantly enhance student collaboration and help them understand subject content better. While in the former case, the device helps students work transparently and simultaneously between groups (Ng et al., 2020), in the latter case, it also supports learning (Lin, KY et al., 2020). Moreover, a digital tool can also be used to identify mathematical talent among primary school pupils based on a computer game (Juric et al., 2021).

In general, the role of digital tools in problem-based STEM learning is

a) it is a problem-solving tool (using the tool to solve the problem).

It is the case for all robotics projects, where the robot has to be "made" to do something (Major et al., 2021; Cui et al., 2021; Wang et al., 2021; Shahin et al., 2021; Sisman et al., 2022; Bhuyan et al., 2020; Kim et al., 2021). However, it also includes programming tasks (Weng et al., 2022; Century et al., 2020; Lin, YT et al., 2020), computer games (Juric et al., 2021), and virtual reality (Darayathna et al., 2020).

b) helps with collaboration

It is either achieved by having to solve the task together, for example, in robotics cases (Major et al., 2021; Cui et al., 2021; Wang et al., 2021; Shahin et al., 2021; Sisman et al., 2022; Bhuyan et al., 2020; Kim et al., 2021) and the science simulation programming task (Lin, YT et al., 2020). Or it can be implemented by making the simultaneous work transparent and assessable, as in the case of the interactive online whiteboard (Ng et al., 2020)

c) supports learning (provides an environment that helps understand the subject content)

We saw examples of this in the use of computer games (Juric et al., 2021), computer agents (Lin, KY et al., 2020), and virtual reality (Dayarathna et al., 2020).

General characteristics of RQ4 (the type of problems)

In this chapter of the study, we want to answer the question of what problems the students had to solve during the STEM education supported by PbL-based digital tools. We grouped the cases into three broad categories based on the problems found in the articles reviewed. These large groups were: real-world problems (15 problems in 7 articles), subject-specific problems (8 problems in 7 articles), and robot operations (3 problems in 3 articles). Within the categories, we also separated subcategories for clarity. In this way, we separated the socially relevant problems, building or designing problems, and financial management problems within real-world problems. Most of the subject-specific problems were related to mathematics. However, we also found one example that was related to biology and two that were related to physics. Two of the three robot operation problems were based on gamification, and one was embedded in project-based learning. A summary of the general characteristics of RQ4 is shown in *Table 4*.

Table 4: The types of problems appeared in PbL STEM using by some kind of digital devices

Categories	Sub-categories	The specific examples	Articles
Real world problems	socially relevant problems	mapping the geographical landscape suitable for plant production	Bhuyan et al, 2020
		finding landfills in uninhabited areas	Bhuyan et al, 2020
		planning a safe route for the school bus after flooding	Bhuyan et al, 2020
		medical transport to the community in case of emergency	Bhuyan et al, 2020
		helping hospitals prioritize patients	Shahin et al, 2021
		helping people who have trouble communicating their food allergies when they travel overseas	Shahin et al, 2021
	building or designing problems	building shelves	Lin, KY et al, 2020
		making a thermometer	Cui et al, 2021
		making a room capacity detector	Cui et al, 2021
		designing a desktop tidy	Lin, KY et al, 2020
		creating a machine, that calculate a bank deposit	Cui et al, 2021
	financial management problems	buying a mobile phone	Lin, KY et al, 2020
		saving money	Weng et al, 2022
		creating a machine, that calculate a bank deposit	Cui et al, 2021
		how business works	Century et al, 2020
Subject-specific problems	mathematical problems	operating with Roman numbers	Juric et al, 2021
		solving calculus problems	Ng et al, 2020
		fractal drawing	Weng et al, 2022 Lin, YT et al, 2020
		prime and composite number detector	Cui et al, 2021
		queuing theory	Dayarathna et al, 2020
	biological problem	DNA string matching	Lin, YT et al, 2020
	physical problem	testing Hook's law	Major et al, 2021
		one-dimensional kinematic problems	Lin, YT et al, 2020
Robot operation	based on gamification	building a robotic arm	Wang et al, 2021
		rolling a robot ball along a defined path	Kim et al, 2021
		sumo robot championship	Sisman et al, 2022

Real-world problems
Real-world problems are prevalent in digital PBL-based STEM education. These include problems arising from everyday difficulties. For example, in a study by Bhuyan et al. (2020), students are looking for solutions to socially fundamental problems such as finding landfills or finding land suitable for growing crops. Moreover, this project involved students from minority, disadvantaged socio-economic

backgrounds. The students in Shahin et al.'s (2021) study had to approach it from a different perspective, also looking for solutions to socially significant problems. They took on an entrepreneurial role in trying to offer solutions to hospitals in prioritizing patients. Lin, KY et al. (2020) and Cui et al. (2021) write in their paper about several problems related to design and creation, like making a thermometer or designing a room capacity detector.

Responsible financial management is a real-world issue. Within this, we encountered problems such as saving money (Weng et al., 2022), bank deposits (Cui et al., 2021), responsible shopping (Lin, KY et al., 2020), or business working (Century et al., 2020).

Subject-specific problems
Here we included problems related to the learning of subject content. Most of them have a mathematical focus, like Roman numbers among elementary school students (Juric et al., 2021), fractal drawing (Weng et al., 2022), and prime and composite number detectors (Cui et al., 2021) among secondary school students. Furthermore, the students' digital STEM PbL exercises were based on topics such as solving various calculus problems (Ng et al., 2020) and queuing theory (Dayarathna et al., 2020).

Technical high school students tested Hooke's law in Major et al. (2021) study. Lin et al. (2021) report on one-dimensional kinetic problem solving by science students. Also, the last paper reports on one-dimensional kinematic problem-solving.

Robot operation problems
First, we would like to clarify that studies, where robotics was merely a tool to achieve a goal were classified in one of the upper categories. In this section, we have only included studies where the ultimate goal of the problem-solving was a particular movement of the robot. Two of these three studies were based on gamification, such as the sumo robot tournament (Sisman et al., 2022) and robot ball path planning (Kim et al., 2021). Moreover, Wang et al. (2021) write about a robot design and construction project among undergraduate students.

Discussion on RQ4
Schools are often criticized for having little to do with everyday life. Nevertheless, exposing pupils to real-world problems is essential as early as possible. Reflecting on socially relevant problems can lead to a change in attitudes towards social engagement, as seen in Bhuyan et al. (2020) study. In addition, it is also imperative for students to understand how, for example, a socially relevant problem can be used to build an enterprise (Shahin et al., 2021). However, not only future entrepreneurs but also engineers and designers are now in school, so various creative tasks (Cui et al., 2021; Lin, KY et al., 2020) and design tasks (Lin, KY et al., 2020) are also of great importance.

Good money management is part of responsible living. Unfortunately, in Hungary, students in public education have little (if any) exposure to money management. However, the articles reviewed provide good examples of money management (Weng et al., 2022; Cui et al., 2021), prudent purchasing (Lin, KY et al., 2020), and the functioning of business (Century et al., 2020).

Based on the reviewed articles, mathematics subject-specific content seems the most difficult to embed in an integrated STEM problem. While all digital PbL STEM studies on social, environmental, or even robotics have mathematics as a tool in the background, the learning of mathematical content is most often done through subject-specific mathematical problem solving (Ng et al., 2020; Cui et al., 2021; Weng et al., 2022). However, digital tools can help to provide a more pleasant user experience for this learning (Dayarathna et al., 2020).

Problem-solving on how to operate robots fosters collaboration between students. These situations also create a natural working environment by jointly operating the robot while solving various

problems and resolving conflicts (Wang et al., 2021). At the same time, robotics can be used to develop a deeper understanding of different subject content, as was the case with the topic of angle pairs, which was aided by designing the path of the robot ball (Kim et al., 2021). Furthermore, the competitive and gamification environment can motivate students to operate the robots more (Kim et al., 2021; Sisman et al., 2022).

A significant finding of Century et al.'s (2020) study on problem-based STEM education supported by digital tools. In a comprehensive, longitudinal study, the authors found that this type of learning performs as well as traditional learning in the subject content. In addition, they develop a range of skills, an integrated approach to science, learn about social problems and develop a different work ethic.

Conclusion

This study presented a systematic literature review revealing the current trends and developments in applying digital tools and implementing environmental awareness and sustainability in PBL-based STEM education. We examined 377 studies published in PBL STEM education from 2020 to 2022. We focused on the types and roles of digital tools, the types of problems solved with digital tools, the types of tools and methods used for environmental awareness and sustainability, and the critical factors for successful implementations.

Our study showed that besides entirely empirical studies, in some particular cases, the general testing, development, and calibration of specific frameworks, methods, or tools can also largely contribute to the effectiveness of the implementation of new environmental awareness- or sustainability-related topics and problems. We found that the most critical factors to success were partly systematic (clearly set goals and policies, state-of-the-art tools and instruments for development, effective assessment system) and partly (inter)personal (role of communities and horizontal networks, lesson planning of the teachers). The results of the SWOT analysis of the implementation of PBL (based on the articles of this study) were consistent with previous ones concerning PBL itself. It also showed that PBL has immense opportunities to help the schools and teachers develop the learners' soft skills, metacognitive skills, and met practical functions.

In our research, we also concluded that problem-based STEM learning in the last two years is most often conducted in a digital environment or with the help of a digital tool. Robotics and programming are the most popular of these. We also found that PBL supported by digital tools is more effective in collaboration than the non-digital version. The digital environment is not only helpful in improving attitudes towards computers or in promoting computational thinking. Nevertheless, it is also a suitable environment for solving problems relevant to everyday life - be it a socially relevant problem, a design-creation task, or even money management. One of the key findings of our research is that digital problem-based STEM learning does not continuously improve students' subject-specific knowledge, but it does not make it worse. However, it does develop skills and abilities such as collaboration, work ethic, creativity, critical thinking, and communication.

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