Identifying ‘best practices’ in education:

Findings from a literature review

Final Report

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1. Executive summary

1.1 Overview of the findings

This report is concerned with detailing the processes involved in teaching; this was accomplished through an analysis of existing research literature. It was recognised at the outset of the study that teachers engage with teaching and learning in three related but different ways. They are concerned with processes involving: pedagogic principles (how they think about the background philosophies and objectives of their teaching); teaching practices (how they might plan for their teaching and their students' learning); and instructional approaches (how they might construct specific lessons and activities, who is involved in doing what, and what outcomes are desired).

The literature review and subsequent analysis drew out specific features and factors that relate to these three areas of teaching concern. Within the area of 'teacher thinking', two aspects of concern were identified – pedagogic principles (such as problem-based learning, or experiential learning) and pedagogic objectives (such as collaboration, or design). Within the area of 'teacher planning', a range of teaching practices were identified that link to pedagogic principles and objectives (such as designing activities, or ensuring equitable student access). Within the area of 'teacher doing', two main concerns were identified – instructional approaches, and pedagogic outcomes. The concern with instructional approaches was further divided into two sub-categories – higher order (general approaches that were taken, such as grouping students, or moderating feedback), and lower order (more specific approaches that were taken, such as asking for student feedback, or time and ways for reviewing and modifying prototypes).

A way to visualise these features, concerned with ways that teachers work, is shown in Figure 1.

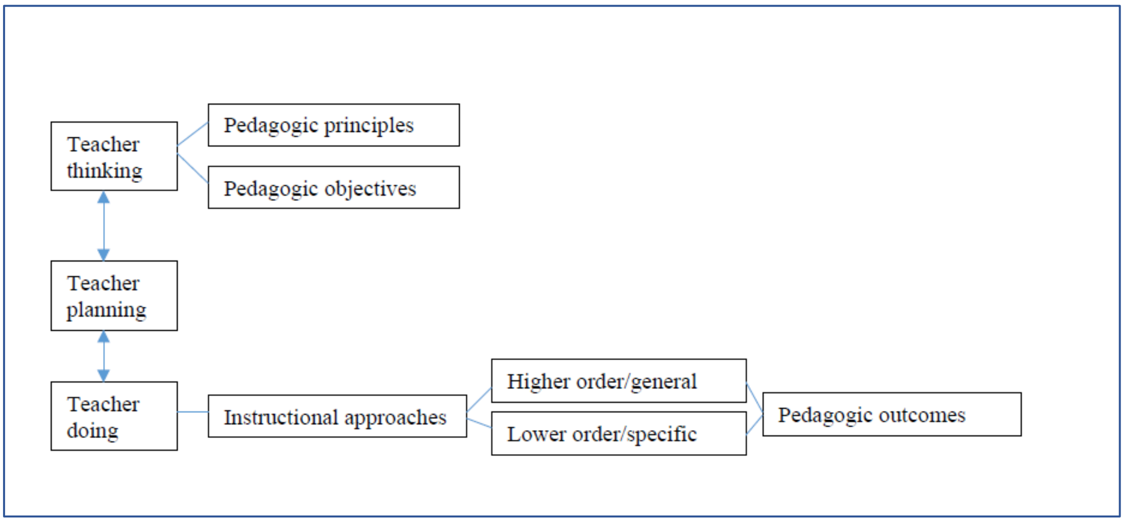

Figure 1: A Framework of the Pedagogic Features explored in the Report

1.2 Applying the findings to practice

Using this overall framework shown in Figure 1, teachers might wish to use the details in this report to explore ways to consider their teaching. However, the ways that the details might be used could well depend on the experience that teachers already have.

For example, an experienced teacher might wish to use Figure 1 to consider some pedagogic principles regarded as strengths and those regarded as less developed or used in their teaching. Choosing pedagogic principles that might be less used, it would be possible then for the teacher to explore the details from the figures and tables, to show how such principles might link to existing teaching approaches, but the details might suggest ways to develop additional teaching practices and instructional approaches.

On the other hand, a less experienced teacher might start with pedagogic outcomes that are felt would be worth exploring, and from these, work backwards to consider details about possible instructional approaches, related teaching practices and ways of thinking through pedagogic principles. In this way, a less experienced teacher might develop their thinking through a doing and planning route; an experienced teacher might develop their practice by exploring their thinking perspectives before looking at possible planning and doing approaches.

1.3 Limitations of the report

This report offers a structured way to consider teaching and the various processes that teachers take on board before they are directly involved in lessons and activities with students. It considers processes that teachers use prior to direct engagement, which enable the teacher to relate fundamental approaches to learning through their teaching. When teachers are in lessons, and students are engaged in activities, there are occasions, of course, when teachers need to 'think on their feet'. This might happen when students raise questions, or when unexpected problems arise. This report and the detail included is not focused on this area of teaching need; identifying teaching processes involved in 'thinking on your feet' would be a separate research focus, which goes beyond the scope of this research report.

2. Background to this literature review study

Much research literature has been devoted to identifying ‘best practices’ in education. Some of this literature has looked at ‘best’ pedagogic principles (such as developing collaborative learning practices, supporting questioning approaches, regular assessment, or self-reflection by students). Other literature has focused on teacher practices that ‘best’ support these pedagogic principles (such as using interactive whiteboards to encourage peer teaching, using question banks that provide instant feedback and teacher monitoring facility, using response devices to gain a picture of class and individual student understanding, or using highlighted texts to support student focus on key elements on which to review and reflect). What the literature is more limited in providing is detail of how the teacher undertakes these teaching practices (through instructional approaches) to support pedagogic principles.

The aim of this research is, therefore, to explore this field further – to provide a framework that shows the ‘best’ pedagogic principles highlighted by the research, the ‘best’ teacher practices to support these, and the ‘best’ instructional approaches to implement them.

In order to achieve this outcome, the research, focusing on appropriate literature reviews and analyses, will be undertaken in three phases: the elicitation of ‘best’ pedagogic principles; the identification of ‘best’ teaching practices; and the description of ‘best’ instructional approaches. This review will explore research that has gathered evidence internationally but has sought to draw on the research literature from the widest possible geographic regions across the world.

To support teacher professional development, the overall outcome of this review will seek to provide evidence that can be constructed in ways for teachers and teacher educators to ‘think’ about their practice, to ‘plan’ for learning activities and to identify what they and learners ‘do’ through engagement in lessons.

2.1 The aim

What we examine in this review is:

- What are the ‘best’ pedagogic principles and the ‘best’ teaching practices that most affect positive student outcomes across the 4-18-year-old (K-12 grade) levels and curriculum areas, as identified by the research literature?
- How can each element of ‘best’ teaching practice be described in terms of ‘best’ instructional approach?
- How, according to strongest possible evidence from the research, do teachers ‘best’ implement instructional approaches that support teaching practices and pedagogic principles using digital technologies[1] to improve student learning outcomes?
- How can the outcomes of the three aims be integrated into a framework to support educators and teachers?

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[1] In the educational research literature context, digital technologies refer largely and most often to hardware, such as student devices, teacher devices, front of room displays, but also to resources such as online video conferencing, software, etc. The remainder of this proposal adopts this form of definition of digital technologies.

2.2 The research question

The overarching research question of this review is: How, according to strongest possible evidence from the research, are instructional 'best' approaches with teacher practices and pedagogic principles integrated to ensure, as far as possible, the effective uses of digital technologies to help improve student learning outcomes?

2.3 The objectives

The research was divided into three phases:

- A literature review to elicit up to 25 'best' pedagogic principles that positively affect student outcomes across the 4-18-year-old (K-12 grade) levels and curriculum areas.
- Identifying the 'best' teacher practices that relate to each of the 25 pedagogic principles.
- Describing for each teacher practice, one or more examples of 'best' instructional approaches that show how a teacher has implemented this within a classroom environment, using digital technologies.

2.4 The research process

The research was undertaken in three phases:

- **Phase 1.** Initially, a literature review was conducted, which searched for evidence of 'best' pedagogic principles. This literature review focused on meta-analyses and more recent studies, including any arising from reviews from practices during the pandemic period, which offered a source of evidence that itself drew from wide ranges of existing literature, and extracted key elements. These meta-analyses and additional studies ensured that pedagogic principles identified accommodated outcomes associated with wide uses (beyond but not excluding those where digital technologies were used). From the range of meta-analyses and additional studies reviewed, up to 25 'best' pedagogic principles were identified (generally, either by frequency of report, or by strength of statistical outcome).
- **Phase 2.** The references within the meta-analyses and additional studies were used to select relevant literature relating to the identification of 'best' teacher practices. This part of the review required specific selection of sources, as a search of this nature often identifies a range of literature that is not entirely pertinent to the topic being explored. Each of the pedagogic principles were exemplified with a number of 'best' teacher practices, identified from the literature reviewed from the meta-analysis and additional sources. The literature was extended to sources arising from the pandemic period, as there were no known meta-analyses that explored teacher practices at that time. These teacher practices covered those concerned with wide uses, beyond but not excluding the range where digital technologies were used.
- **Phase 3.** The third phase of the review required an analysis of the literature identified in the second phase, drawing out 'best' instructional approaches for each teacher practice listed. From the relevant literature sources, together details describing the instructional approach, demographic details of the education/school type, educational level, population and size, location, and region, all listed where these details were provided.

3. Literature review overview

3.1 Scope of the literature review

The scope of the initial literature review is shown in Table 1. Table 1 shows the author(s), titles, age range of students involved in each of the published studies, location(s) of the study, and the study field. The review has taken evidence from across the age range, from across geographical and regional locations, and from across subject fields.

Table 1: Details of the Literature reviewed in the Report

	Author(s)	Title	Age range	Location(s)	Subject field
1.	(Chen, Chen, & Wang, 2022)	Creative Situated Augmented Reality Learning for Astronomy Curricula	Fifth and sixth grade	Taiwan	Astronomy
2.	(Jocius, Albert, Andrews, & Blanton, 2020)	A study in contradictions: Exploring standards-based making in elementary classrooms	1st, 2nd, 3rd, 4th, and 5th grades	USA	Mobile Maker Kit lessons
3.	(Kajamaa & Kumpulainen, 2020)	Students' multimodal knowledge practices in a makerspace learning environment	Primary level	Finland	STEAM
4.	(Ladachart, Radchanet, & Phothong, 2022)	Design thinking mindsets facilitating students' learning of scientific concepts in design-based activities	Seventh to twelfth - grade students'	Turkey	STEM
5.	(Liston, 2022)	Designing and building toys: A model of incorporating both the engineering design and design thinking processes in the elementary classroom	10 to 12 years old	Ireland	Designing and building toys (STEM)
6.	(Lottero-Perdue & Lachapelle, 2020)	Engineering mindsets and learning outcomes in elementary school	10 to 11 years old	USA	Engineering education
7.	(Muramatsu, Wangmo, & Wangchuk, 2019)	e-Design education using a 3d printer based on design thinking at primary school	Primary school students	Bhutan	E-design education
8.	(Panskyi & Rowińska, 2021)	A holistic digital game-based learning approach to out-of-school primary programming education	Primary school students	Poland	Game-based learning (Programming education)
9.	(Scott, Pilla, Keeffe, & White, 2021)	STEM through inquiry projects for students: A teacher's perspective	Years 7 and 8	Australia	STEM education

	Author(s)	Title	Age range	Location(s)	Subject field
10.	(Sinervo et al., 2021)	Elementary school pupil's co-inventions: products and pupil's reflections on processes	11-13 years old	Finland	Digital and traditional fabrication technologies
11.	(Stehle & Peters-Burton, 2019)	Developing student 21st century skills in selected exemplary inclusive STEM high schools	Grades 11 and 12	USA	STEM
12.	(Sun, Chang, & Chiang, 2022)	When life science meets educational robotics: A study of students' problem solving process in a primary school	Fifth graders 10 to 11 years old	Shanghai	Life sciences
13.	(Wendell, Andrews, & Paugh, 2019)	Supporting knowledge construction in elementary engineering design	Elementary Fourth and Fifth graders	USA	Engineering design
14.	(Wu & Liu, 2022)	Effectiveness of remote-control cars and authentic learning in strengthening creative thinking and problem-solving abilities	Second grade elementary 7 to 8 years old	Taiwan	Remote-control cars
15.	(Yang, Long, Sun, Van Aalst, & Cheng, 2020)	Fostering students' creativity via educational robotics: An investigation of teachers' pedagogical practices based on teacher interviews	Grades 4 and 6	China	Educational robotics
16.	(Hall & Thomson, 2016)	Creativity in teaching: what can teachers learn from artists?	Primary and Secondary	UK	STEAM
17.	(Noel & Liu, 2016)	Using Design Thinking To create a new Education paradigm For elementary level Children for higher Student engagement And success	Primary school level	USA	Mathematics and language arts
18.	(Means, Toyama, Murphy, & Baki, 2013)	The effectiveness of online and blended learning: A meta-analysis of the empirical literature	13 to 44 years old	Not mentioned	Computer science, teacher education, social science, mathematics, languages, science, and business

	Author(s)	Title	Age range	Location(s)	Subject field
19.	(Tamim, Bernard, Borokhovski, Abrami, & Schmid, 2011)	What forty years of research says about the impact of technology on learning: A second-order meta-analysis and validation study	Secondary and Primary	Not mentioned	Combination Science and health Language Mathematics Information Literacy Engineering Science and health Language
20.	(Borokhovski, Tamim, Bernard, Abrami, & Sokolovskaya, 2012)	Are contextual and designed student-student interaction treatments equally effective in distance education?	Not mentioned	Not mentioned	Not mentioned
21.	(Margulieux, McCracken, & Catrambone, 2015)	Mixing in-class and online learning: Content meta-analysis of outcomes for hybrid, blended, and flipped courses	Higher Education *	Not mentioned	Mathematics
22.	(Hattie & Timperley, 2007)	The power of feedback	Not mentioned	Not mentioned	Mathematics English
23.	(Wisniewski, Zierer, & Hattie, 2020)	The power of feedback revisited: A meta-analysis of educational feedback research	Kindergarten, primary school, secondary school, college or university	Not mentioned	English Mathematics Science
24.	(Garzón, Kinshuk, Baldiris, Gutiérrez, & Pavón, 2020)	How do pedagogical approaches affect the impact of augmented reality on education? A meta-analysis and research synthesis	All	Not mentioned	Mathematics English Arts and Humanities Social sciences
25.	(Rice, 2022)	Special Education Teachers’ Use of Technologies During the COVID-19 Era (Spring 2020—Fall 2021)	Kindergarten, grade 3, grade, 6, and grade 10.	USA	Special education
26.	(Nisiforou, Kosmas, & Vrasidas, 2021)	Emergency remote teaching during COVID-19 pandemic: lessons learned from Cyprus	K-12	Cyprus	General

	Author(s)	Title	Age range	Location(s)	Subject field
27.	(Mahbub, Seraj, Chakraborty, Mehdi, & Roshid, 2022)	A Systematic Review on Pedagogical Trends and Assessment Practices during the COVID-19 Pandemic: Teachers' and Students' Perspectives	Not mentioned	Not mentioned	Not mentioned
28.	(Liu & Zhao, 2022)	Meta-analysis of effectiveness of electroencephalogram monitoring of sustained attention for improving online learning achievement	Junior high school High school	Malaysia	English Antiphishing Virtual reality
29.	(Bishop, 2021)	Middle Grades Teacher Practices during the COVID-19 Pandemic	Middle grades	Not mentioned	English language arts; mathematics; science; social studies; special education.
30.	(Crompton, Burke, Jordan, & Wilson, 2021)	Support provided for K-12 teachers teaching remotely with technology during emergencies: A systematic review	K-12	UK, Australia, Belgium, Cyprus, Ireland, and the Netherlands (52 countries)	Mathematics
31.	(Spitzer & Musslick, 2021)	Academic performance of K-12 students in an online-learning environment for mathematics increased during the shutdown of schools in wake of the COVID-19 pandemic	K-12	Germany	Mathematics

4. Phase 1: Pedagogic principles

4.1 The pedagogic principles

In total, 25 pedagogic principles were identified from the literature review, all principles that support a range of learning outcomes. These 25 pedagogic principles are listed here, with definitions arising from the existing literature.

4.1.1 Design-based learning:

This pedagogic principle focuses on design-based tasks that include learning through: 1) analysing the situation, 2) defining the problem, 3) modelling ideas, 4) designing solutions, 5) predicting results, 6) questioning unexpected outcomes, and 7) managing the designing process (Ladachart et al., 2022).

4.1.2 Problem-based learning:

This pedagogic principle focuses on enabling students to gain systematic, mechanical, and complex skillset in order to use knowledge for solving problems (Aslan & Duruhan, 2021; Sun, Chang, & Chiang, 2022).

4.1.3 STEM toys:

This pedagogic principle focuses on using toys for learning using science, technology, engineering, and mathematics (STEM) (Coyle & Liben, 2020).

4.1.4 Group learning:

This pedagogic principle focuses on group members where each is responsible for the entire group's work (Lestari & Ariesta, 2020).

4.1.5 Multimedia learning:

This pedagogic principle focuses on presenting words and pictures to enhance learning through building mental representations of objects. Multimedia learning uses animations, digital games, static graphics, and interactive simulations (So, Chen, & Wan, 2019).

4.1.6 Reflective learning:

This pedagogic principle focuses on students' analysis and conscious thinking towards previous learning activities (Daradoumis & Arguedas, 2020).

4.1.7 Collaborative game-design learning:

This pedagogic principle focuses on teamwork, joint reflection, and collaborative creation of knowledge (Laakso, Korhonen, & Hakkarainen, 2021).

4.1.8 Engineering design learning:
This pedagogic principle focuses on solving problems iteratively for improving the solution based on received feedback (Lottero-Perdue & Lachapelle, 2020).

4.1.9 Exploratory learning:
This pedagogic principle focuses on the deep reflection after the practices of learning (Freitas & Neumann, 2009; Lottero-Perdue & Lachapelle, 2020).

4.1.10 Simulative-based learning:
This pedagogic principle focuses on making the invisible visible for helping students learn sophisticated concepts (Alfred, Neyens, & Gramopadhye, 2018; Sarwoto, Jatmiko, & Sudibyo, 2020).

4.1.11 Inquiry-based learning:
This pedagogic principle focuses on enabling students to think critically and develop their skills for discovering concepts through the use of different approaches to solve problems (Maryani, Lestari, & Saifuddin, 2019).

4.1.12 Experiential learning:
This pedagogic principle focuses on developing concepts by reflecting on experiences that can be used as guidelines for successive experimentations (Healey & Jenkins, 2000; Sumarmi et al., 2020).

4.1.13 Feedback-based learning:
This pedagogic principle focuses on providing information to students using agents such as book , peer, teacher, peer, self, parent, and/or experience concerning one's understanding or performance (Griffith, Johnson, Larson, & Buttitta, 2020; Maier, 2021).

4.1.14 Inclusive learning:
This pedagogic principle focuses on practices that use service-learning and learning communities projects (López-Azuaga & Suárez Riveiro, 2020).

4.1.15 Service learning:
This pedagogic principle focuses on preparing students to use their skills and knowledge and skills to solve authentic problems in communities outside schools (Rimm-Kaufman et al., 2021).

4.1.16 Learning by modelling:
This pedagogic principle focuses on organising and converting students' knowledge to form computational structures that can be put into practice to generate model behaviors (Hutchins et al., 2020).

4.1.17 Contextual learning:
This pedagogic principle focuses on situating learners in meaningful learning contexts (Sung, Hwang, Chen, & Liu, 2022).

4.1.18 Digital game-based learning:
This pedagogic principle focuses on engaging students in an activity that teaches somewhat valuable or produces a common good to the player through focusing their attention using elements of fantasy, challenge, and curiosity (Yeh, Sai, & Chuang, 2020).

4.1.19 Story-based learning:

This pedagogic principle focuses on the use of stories for enhancing feelings of relatedness (Yeh et al., 2020).

4.1.20 Inter-cultural learning:

This pedagogic principle focuses on examining culture through dialog and interaction. (Piipponen & Karlsson, 2019).

4.1.21 Mobile/location game-based learning:

This pedagogic principle focuses on connecting students' learning to external environments outside the school using games (Huizenga, Admiraal, Dam, & Voogt, 2019).

4.1.22 Personalised-based learning:

This pedagogic principle focuses on adapting learning content and difficulty level to student's learning abilities (Thai, Bang, & Li, 2022).

4.1.23 Research-based learning:

This pedagogic principle focuses on helping students develop: 1) own research questions, 2) hypotheses, 3) systematic inquiry, 4) data collection tools, 5) analysis of findings, 6) presentations for real audience (Bjørkvold & Ryen, 2021).

4.1.24 Self-regulated learning:

This pedagogic principle focuses on a learning process where students do the following: 1) identify their learning needs, 2) formulate their learning goals, 3) identify their learning resources, 4) choose their learning strategies, and 5) evaluate their learning outcomes (Lloyd, Rieber, 1996).

4.1.25 Open-ended questions learning:

This pedagogic principle focuses on prompting students to reason and reflect by thinking actively to solve problems and make decisions based on data analysis and evaluation (Monrat, Phaksunchai, & Chonchaiya, 2022).

4.2 Sources of evidence

The sources of pedagogic principles in the literature review were from studies that provided supportive evidence of learning outcomes through quantitative, qualitative, or mixed methods approaches, taking numbers of students in the studies into account. These details are shown in Table 2. It should be noted that item 13, 'Interactive learning', was not taken forward as one of the selected 25 principles, as the details were included and integrated within other principles, notably 'Experiential learning'.

Table 2: Details of Supportive Evidence in the Literature reviewed in this Report

Pedagogic principle	Number of students	Qualitative/Quantitative
1. Design-based/Design Thinking learning	38 students (Ladachart et al., 2022)	Quantitative
2. Problem-based learning	69 students (Sun et al., 2022) 68 students (Aslan & Duruhan, 2021)	Mixed method Mixed methods

Pedagogic principle	Number of students	Qualitative/Quantitative
3. STEM toys learning	61 students (Coyle & Liben, 2020)	Quantitative
4. Group learning	44 students (Lestari & Ariesta, 2020)	Mixed methods
5. Multimedia learning	330 students (So et al., 2019)	Qualitative
6. Reflective learning	45 students (Daradoumis & Arguedas, 2020)	Quantitative
7. Collaborative Game-design learning	98 students (Laakso et al., 2021)	Mixed methods
8. Engineering design learning	14,015 students (Lottero-Perdue & Lachapelle, 2020)	Mixed methods
9. Exploratory learning	48 students (Wu & Liu, 2022)	Quantitative
10. Simulative-based learning	40 students (Sarwoto et al., 2020)	Quantitative
11. Inquiry-based learning	43 students (Maryani et al., 2019)	Mixed methods
12. Experiential learning	288 students (Sumarmi et al., 2020)	Quantitative
13. Interactive learning	58 students (Zubiri-Esnaola, Vidu, Rios-Gonzalez, & Morla-Folch, 2020)	Qualitative
14. Feedback-based learning	620 students (Maier, 2021) 49 students (Griffith et al., 2020)	Quantitative Qualitative
15. Inclusive learning	757 students (López-Azuaga & Suárez Riveiro, 2020)	Quantitative
16. Service learning	868 students (Rimm-Kaufman et al., 2021)	Quantitative
17. Learning by modelling	84 students (Hutchins et al., 2020)	Quantitative
18. Contextual learning	38 students (Sung et al., 2022)	Quantitative
19. Digital Game-based learning	82 students (Yeh et al., 2020)	Mixed methods
20. Personalised Learning	453 students (Thai et al., 2022)	Quantitative
21. Intercultural learning	3 schools (Piipponen & Karlsson, 2019)	Qualitative
22. Mobile or location Game-based learning	181 students (Huizenga et al., 2019)	Quantitative

Pedagogic principle	Number of students	Qualitative/Quantitative
23. Research-based learning	36 students (Bjørkvold & Ryen, 2021)	Qualitative
24. Question-based learning	28 students (Monrat et al., 2022)	Mixed methods
25. Self-Regulated Learning	330 students (So et al., 2019)	Qualitative
26. Story-based learning	82 students (Yeh et al., 2020)	Mixed methods

4.3 Relationships of pedagogic principles

From the details gathered and presented in this report, it is clear that there is no one single pedagogic principle that encompasses all others, or indeed that should be regarded as more important or prominent than any of the others. All the pedagogic principles identified have been shown to lead to specific learning outcomes. For a teacher, what is important is the range of pedagogic principles that can be known and applied. In the remainder of this report, the relationship of pedagogic principles is explored, as well as details about associated teaching practices and instructional approaches and outcomes.

It is important to note that all of these pedagogic principles are supportive of educational and learning outcomes. They are not entirely exclusive, as there are features that show relationship between and across these principles.

A "Pedagogic Principles Circuit" (Figure 2) shows how the 26 principles share certain pedagogic objectives (POs): 1) solve problems, 2) inquire, 3) collaborate, 4) interact, 5) reflect, 6) design, 7) research, and 8) link to life. To read the visual, it is necessary to look at it both horizontally and vertically. The circles show whether the PO is met by the pedagogic principle (PP) or not. The white circle means that it is not met (optional), but the black circle means that it is met (mandatory). As a result, the white optional circle might be met if needed, but the black circle must be met by the PP. In addition, the grey squares resemble the 26 PPs. To read the circuit, you can: 1) start with the PP name, and then follow the arrow to know the position of the square that it resembles, 2) follow the circles that are perpendicular on that square to see the mandatory and optional POs that belong to that PP, 3) look horizontally to the left to know the PO name next to the black circle, and 4) look horizontally to see the other PPs that share the same PO by following the squares, and then the arrows to know the names of the PPs that have black circles. For example, design-based learning has certain mandatory POs: 1) solve problems, 2) collaborate, 3) interact, and 4) design. With respect to the PO "interact", we can find all the other PPs share that same PO. However, with respect to the PO "research", we find that the only PPs that share the same PO are simulated learning and research-based learning. The teacher can use this bird's-eye-view visual to orchestrate between the 26 PPs and their objectives in an innovative way by considering and applying the strength of each.

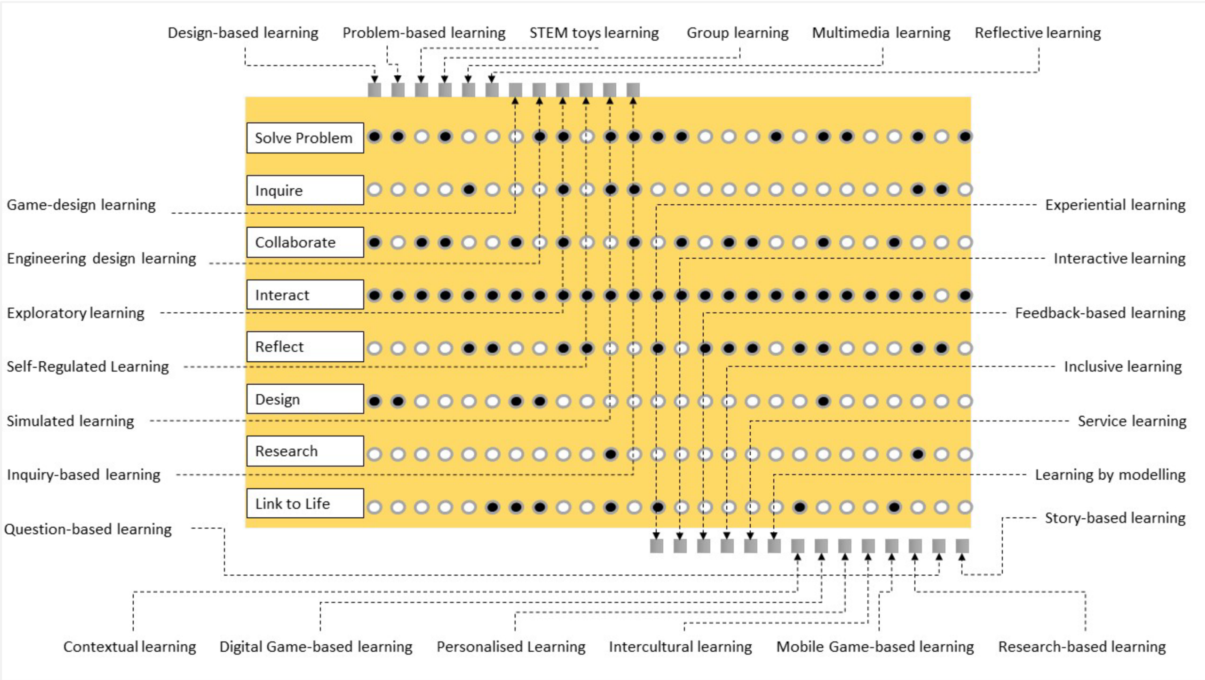

Figure 2: Pedagogic Principles Circuit

Table 3 shows another way of viewing the relationships between the pedagogic principles and the pedagogic objectives.

Table 3: Relationship of Pedagogic Principles to Pedagogic Objectives

	Pedagogic Objectives							
	Solve Problem	Inquire	Collaborate	Interact	Reflect	Design	Research	Link to Life
Pedagogic Principles								
Design-based/Design thinking learning	■	□	■	■	□	■	□	□
Problem-based learning	■	□	□	■	□	■	□	□
STEM toys learning	□	□	■	■	□	□	□	□
Group learning	■	□	■	■	□	□	□	□
Multimedia learning	□	□	□	■	□	□	□	□
Reflective learning	□	□	□	■	■	□	□	□
Collaborative Game-design learning	□	□	■	■	■	■	□	■
Engineering design learning	■	□	□	■	□	■	□	■
Exploratory learning	■	■	■	■	■	□	□	□
Simulative-based learning	■	■	□	■	□	□	■	■
Inquiry-based learning	■	■	■	■	□	□	□	□
Experiential learning	■	□	□	■	■	□	□	■
Feedback-based learning	□	□	□	■	■	□	□	□
Inclusive learning	□	□	■	■	□	□	□	□
Service learning	■	□	■	■	■	□	□	□
Learning by modelling	■	□	□	■	□	□	□	□
Contextual learning	□	□	□	■	■	□	□	■

	Pedagogic Objectives							
	Solve Problem	Inquire	Collaborate	Interact	Reflect	Design	Research	Link to Life
Pedagogic Principles								
Digital Game-based learning	■	□	■	■	■	■	□	□
Personalised learning	■	□	□	■	□	□	□	□
Intercultural learning	□	□	□	■	□	□	□	□
Mobile or location game-based learning	□	□	□	■	■	□	□	■
Research-based learning	■	■	□	■	■	□	■	□
Question-based learning	□	■	□	■	□	□	□	□
Self-regulated Learning	□	□	□	■	■	□	□	□
Story-based learning	■	□	□	■	□	□	□	□

Key	
■ Mandatory objective	□ Optional objective

Figure 3 also shows relationships between pedagogic principles and pedagogic objectives. For each pedagogic principle, the symbols below show the list of eight pedagogic objectives. Some of these are coloured, and some are not coloured (they remain white). For each pedagogic principle, it is possible to consider all pedagogic objectives when designing lessons and activities. However, some pedagogic objectives have been shown through research to be essential if pedagogic outcomes are to be achieved. Those essential elements are coloured; those should always be considered when planning lessons and activities. The other white-coloured pedagogic objectives are optional; they can be considered and included, they may offer additional opportunities for student engagement and learning outcomes, but they are not essential for pedagogic outcomes associated with that principle.

A "Pedagogic Principles Blender" (Figure 3) shows how the 26 PPs share 8 POs: 1) solve problems, 2) inquire, 3) collaborate, 4) interact, 5) reflect, 6) design, 7) research, and 8) link to life. Each PO has a certain icon that it resembles (shown below the figure, Figure 3). For example, the PO "reflect" is resembled by a triangle. When the triangle is coloured, that means that the PO is mandatory, but when it is white, it means that it is optional. Each PP has the 8 POs underneath it; when coloured, that means that the PO should be met by the PP, and when white, then it is optional. For example, problem-based learning includes three POs - "solve problem", "interact", and "design" that are coloured - so they should be met by that PP, while the rest are optional. By observing the coloured PO, the teacher can know which PPs share the same objectives. The teacher can use this bird's-eye-view visual to orchestrate between the 26 PPs and their objectives in an innovative way by applying the strength of each.

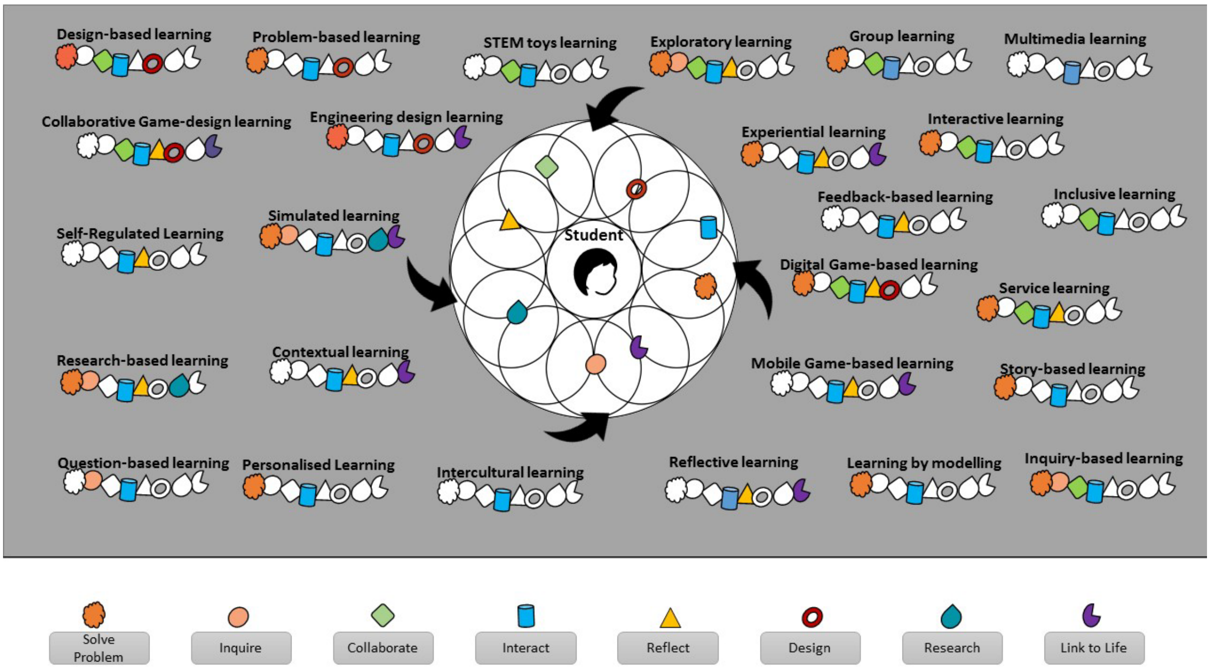

Figure 3: Pedagogic Principles Blender

4.4 Using the literature review evidence to support teachers and teacher professional development

Ways to use this literature review evidence with teachers and for teacher professional development need to explore further, and discussions and decisions about these are beyond the scope of this report. However, as an example, one way to use might be to:

- Select the pedagogic outcome you would like to focus on from the "Pedagogic Principles Circuit" that is shown in Section 3.3.
- Consider the range of pedagogic principles shown on the "Pedagogic Principles Circuit" that relate to this pedagogic outcome and select those that would appear to offer appropriate teaching and learning ideas for activities with students.
- Explore the details relevant to each of those pedagogic principles that are listed in Section 4, the 'Teaching practices. Plan activities using these details.
- Also explore the details relevant to those pedagogic principles that are listed in Section 5, the 'Instructional approaches and outcomes', in order to consider how the activities, focus on what you the teacher and what the students can 'do'.

5. Phase 2: Teaching practices

5.1 Teaching practices related to each of the pedagogic principles

The second phase of the literature review identified, for each of the pedagogic principles, the teaching practices that were described in the studies. In the following sub-sections, for each pedagogic principle, teaching practices and objectives are listed. The study sources are shown below each list of teaching practice details.

5.1.1 Design-based learning:

In this pedagogic principle, teaching practices include the following:

- Designing activities for students to reach the following objectives:
  - Create designs
  - Evaluate outcomes
  - Generate reasons
  - Test ideas
  - Analyse results
  - Generalise results
  - Connect to big ideas
- Connecting learning content to the design challenge and the DBL process to make it more interesting and attractive to students.
- Moderating the complexity of the design challenges during iteration.
- Combining passive listening and hands-on experimentation activities
- Using modern technologies/kits (e.g., Lego-Logo, Lego NXT kits, Scratch, Raspberry Pi, Lilypad) that engage children, triggering their curiosity and building up their enthusiasm.
- Structuring materials and resources (e.g., instructional worksheets) to motivate students and trigger their interest and curiosity in the topics covered.
- Involving various stakeholders (e.g., those with external businesses as clients, involving professionals as experts, and consulting intended users).
- Setting a feasible project time constraint, considering the complexity of the design challenge and the checkpoints during the project.

(Zhang, Markopoulos, & Bekker, 2020) (Gómez Puente, Van Eijck, & Jochems, 2013)

5.1.2 Problem-based learning:

In this pedagogic principle, teaching practices include the following:

- Designing activities for students to reach the following objectives:
  - Identifying needs or a problem
  - Researching needs or problem
  - Developing possible solution
  - Selecting the best possible solution
  - Constructing a prototype
  - Testing and evaluating the solution
  - Communicating the solution
  - Redesigning the solution
  - Completing the solution

(Sun et al., 2022) (Aslan & Duruhan, 2021)

5.1.3 STEM toys:

In this pedagogic principle, teaching practices include the following:

- Play preparation
- Dyadic play
- Post dyadic play

(Coyle & Liben, 2020)

5.1.4 Group learning:

In this pedagogic principle, teaching practices include the following:

- Engaging students in a set of classroom activities in which students work in groups in a coordinated way to solve a given problem
- Sharing ideas and consider the most appropriate response

(Lestari & Ariesta, 2020)

5.1.5 Multimedia learning:

In this pedagogic principle, teaching practices include the following:

- **Forethought phase**: plan for students to make use of texts, dialog cartoons, statistics tables, and tools for communicating to diagnose or share their prior knowledge, set goals, and develop interest.
- **Performance phase**: plan for students to get engaged in activities involving graphics, animations, games, and simulation experiments to learn about scientific knowledge and inquiry processes. Tools involving information processing, organizing, and data collecting are provided for them to better regulate, monitor, or record their learning.
- **Self-reflection phase**: plan for students to complete quizzes to assess their learning. The use of emoticons as positive feedback may increase their satisfaction during the self-assessment process. Tools for asking and discussing or summarizing and conceptualizing are offered to assist students in better conceptualizing what they observed or experienced in the performance phase.

(So et al., 2019)

5.1.6 Reflective learning:

In this pedagogic principle, teaching practices include the following:

- Plan for students to reflect on the way they learn
- Plan for students to reflect on the learning strategies they use
- Plan for students to reflect on the way these strategies have influenced their learning
- Plan for students to review the tasks they have carried out, to think about how they have performed in them, and ultimately how and what they have learned..

(Daradoumis & Arguedas, 2020)

5.1.7 Collaborative game-design learning:

In this pedagogic principle, teaching practices include the following:

- Plan for creating a story-based context
- Plan for guiding practices of creativity strategies
- Plan for using varied types of challenging tasks
- Plan for giving constructive feedback for answers
- Plan for giving free choices of game order and gifts
- Plan for providing immediate feedback regarding obtained scores
- Plan for giving verbal encouragement for performance
- Plan for asking students to do peer evaluation of their creativity designs

(Laakso et al., 2021)

5.1.8 Engineering design learning:

In this pedagogic principle, teaching practices include the following:

- Plan for students to focus their attention on problematic areas of their potential solutions while doing effective diagnostic troubleshooting.
- Plan for students to iterate accordingly as they make improvements based on feedback.
- Plan for students to recognize and analyse design failures, use them to improve the design, and try again

(Lottero-Perdue & Lachapelle, 2020)

5.1.9 Exploratory learning:

In this pedagogic principle, teaching practices include the following:

- **First stage**: Plan for students to participate in inquiry learning, asked questions, and reflect on problems to solve them through discussion with others use the knowledge they had gained.
- **Second stage**: Plan for students to participate in simulated learning activities and engage in role-play activities.
- **Third stage**: Plan for students to identify similarities and differences. The students also participate in peer evaluation.
- **Fourth stage**: Plan for students to learn simple programming and use various technological tools
- **Fifth stage**: Plan for students to record what they had learned, share their experiences, and reflect on their feelings during the process.
- Plan for folding time into learning processes since differentiation and variation happen over time. Plan
- Plan for folding place into the learning process to encounter real events and avoid the expected processes of the already known.
- Plan for folding in movement by blurring the school subjects and work with interdisciplinary and real-life projects.
- Plan for folding the body and the senses in learning situations, thus creating effective learning situations.
- Plan for folding combinations of working methods to examine and disturb habitual ways of thinking.

(Wu & Liu, 2022) (Hellman & Lind, 2021)

5.1.10 Simulative-based learning:

In this pedagogic principle, teaching practices include the following:

- Designing activities for students to reach the following objectives:
  - Observing activities to identify things they want to know
  - Formulating questions and hypotheses
  - Collecting data with various techniques
  - Associating/analysing/processing data (information)
  - Drawing conclusions
  - Communicating the results which consist of conclusions to obtain knowledge, skills, and attitudes

(Sarwoto et al., 2020) (Pellas, Mystakidis, & Kazanidis, 2021

5.1.11 Inquiry-based learning:

In this pedagogic principle, teaching practices include the following:

- Plan for creating a peer environment focusing on physical skills.
- Plan for the implementation of a learning strategy that allows interaction and working with peers to ensure the development of social personality for the students
- Plan for the formulation of activities with emphasis on providing concrete or immediate experiences in building concept
- Plan for the application of value-developing learning process to ensure the students are self-reliant and independent

(Maryani et al., 2019)

5.1.12 Experiential learning:

In this pedagogic principle, teaching practices include the following:

- Designing activities for students that include:
    - Stages of real experience
    - Stages of reflection observation
    - Stages of conceptualization
    - Stages of implementation
- Creating a social situation which facilitates students' engagement in the learning activity.
- Providing necessary learning support throughout the lessons.
- Ensuring equitable student access to resources and learning opportunities.
- Forming pairs based on learners' knowledge, learning characteristics, and behaviours.

(Sumarmi et al., 2020) (Cheng, Hwang, & Chen, 2019) (Falloon, 2019)

5.1.13 Feedback-based learning:

In this pedagogic principle, teaching practices include the following:

- Plan for expressing the merits and faults of learners' work
- Plan for allowing learners to see areas for improvements and progress already made

(Maier, 2021) (Griffith et al., 2020)

5.1.14 Inclusive learning:

In this pedagogic principle, teaching practices include the following:

- focusing on all learners, where learning opportunities are available to everyone, so that students participate in classroom life
- Considering difference as an ordinary aspect of human development, and this includes differences of gender, disability, special educational needs, ethnicity, class, immigration status, sexuality, etc
- Considering diversity to be accepted as a natural and inevitable circumstance with which we must learn to work, tailoring our teaching to the needs of heterogeneous groups.
- Avoiding practices that involve comparison, ranking or labelling, and beliefs about fixed abilities
- Adopting a "personalized" approach to teaching and learning where teachers adapt approaches and resources to each individual learner's needs
- Ensuring a balance between on-going formative assessment and summative assessment, as part of everyday classroom practice
- Including targeted goals, alternative routes for learning, and flexible instruction Plan
- Including cooperative and dialogic activities
- Including collaborative problem-solving as an effective strategy to promote inclusion. Plan
- Providing structured instruction/teaching (i.e., sequences with clear goals, identifying critical aspects of the subject in focus, mentoring, follow-up on the learners' understanding, summaries, synthesis, and repetition)
- Providing meta-cognitive strategies (i.e., the methods of studying, learning, building on the principles of organising an assignment for self-learning, self-evaluation, support from a partner, repetition, and memorising, formulating goals, and planning for future learning).
- Providing instructional practices.
- Providing organisational practices.
- Providing collaboration and teamwork activities.
- Providing social, emotional, and behavioural practices.

(López-Azuaga & Suárez Riveiro, 2020) (Kefallinou, Symeonidou, & Meijer, 2020) (Finkelstein, Sharma, & Furlonger, 2021)

5.1.15 Service learning:

In this pedagogic principle, teaching practices include the following: • Creating norms and teaching social skills to create a sense of community and prepare for collaborative work. • Teaching the privileges and responsibilities that come with being an engaged citizen of their community. • Enacting lessons to teach active listening, respectful communication, and respect for multiple perspectives. • Launching lessons that guide students to discuss and debate using their newly acquired social skills. • Assessing students' science learning in this step. • Designing activities for students to work together to propose solutions. • Using lessons to help students understand different ways their class can make a difference in the world. • Designing activities for students to plan a project. • Designing activities for students to implement the project. • Planning for assessing the impact of their project. • Designing activities for students to reflect on: New knowledge and the service-learning process experience, lessons focused on social and emotional skills are interspersed throughout so that students learn the skills needed to communicate effectively, work together with others on a project, reflect and make decisions, and resolve conflicts that arise. • Recruiting and collaborating with community members throughout the development and enactment of the service project. • Relying on student voice at every step. • Strengthening students' relationships with the community. • Allowing students to actively engage in solving real-world needs and to take time for critical reflection.
(Rimm-Kaufman et al., 2021) (Gartland, 2021) (Resch & Schrittesser, 2021)

5.1.16 Learning by modelling:

In this pedagogic principle, teaching practices include the following: • Designing activities for students that include: o Organising and converting knowledge of concepts into computational structures that can be executed to generate model behaviours. o Doing step-by-step execution linked to animations of model behaviour and plots of variable values as a function of time • Providing scaffolds for interpreting and understanding the modelled phenomena.
(Hutchins et al., 2020)

5.1.17 Contextual learning:

In this pedagogic principle, teaching practices include the following:

- Presenting contexts or storyline (Show the background story)
- Conceptualising the contexts (Present the core concepts)
- Making connections (Conduct learning tasks for connecting the concepts and storylines)
- Practicing and reflecting (Conduct test and provide feedback)
- Integrating science content with other content and areas of expertise
- Undertaking activities that will guide students toward discovery
- Selecting and adapting curriculum

(Sung et al., 2022) (Dewi & Primayana, 2019) (Suryawati & Osman, 2018) (Glynn & Winter, 2004)

5.1.18 Digital game-based learning:

In this pedagogic principle, teaching practices include the following:

- Plan for students to themselves design and draw all the characters and environments in their games
- Plan for students to themselves construct the scripts
- Plan for students to themselves design and create sounds
- Plan for students to themselves program the entire game as a functional system

(Yeh et al., 2020)

5.1.19 Story-based learning:

In this pedagogic principle, teaching practices include the following:

- Using of story scenario, videos, and animations (to increase fun and motivation)
- Scaffolding of learning (to guide practices of creativity strategies and dispositions)
- Using self-determination (free choices of game order)
- Encouraging goal setting
- Varying levels and types of challenging tasks
- Providing constructive feedback and verbal encouragement for performance
- Using observational learning (through peer evaluation of creativity design)
- Providing activities that include videos and animations (to increase fun and motivation)

(Yeh, Chang, & Ting, 2022) (Bidari, 2019) (Yeh et al., 2022)

5.1.20 Inter-cultural learning:

In this pedagogic principle, teaching practices include the following:

- Using narrative and dialogue in curricular planning
- Using telling and listening to each other’s stories to increase awareness of themselves and others
- Taking students' teaching-related wishes, problems, and criticism seriously
- Taking into consideration students' own experiences

(Piipponen & Karlsson, 2019)

5.1.21 Mobile/location game-based learning:

In this pedagogic principle, teaching practices include the following:

- Designing activities for students that include:
    - Collaborate with their peers or in groups
    - Navigate through the environments
    - Engage with game elements, such as the mission, characters, and story
    - Use mobile devices with wireless network connections, cameras, RFID readers and GPS (expands learning with games from the screen to learning in a mixed-reality environment using urban spaces as a game board.
- Provides a guiding, supervisory roles, and later discussed the critical notion of teachers 'releasing control' to encourage students' independent learning, allowing them "to explore, make mistakes, and learn from them; all this, while they are out of the classroom's walls
- Designing tasks that were highly authentic and meaningful for students such as a visit to a biotic drink factory where students learned about the presence of good bacteria and how it travels through their digestive systems.
- Delivering less content and provides more learning tasks related to the environment

(Huizenga et al., 2019) (Burden, Kearney, Schuck, & Hall, 2019) (Chung, Hwang, & Lai, 2019)

5.1.22 Personalised-based learning:

In this pedagogic principle, teaching practices include the following:

- A teaching portion that provides a brief overview of the game, the problem-scenario, and instructions on the mathematics content needed to successfully solve the problem or complete the presented task.
- A teaching portion that explains the content and tells students which actions to take.
- Scaffolding to provide help for students while working.
- Using scaffolding mechanism to enable each student to have a completely personalized experience, tailored precisely to his or her "ready to learn" level and learning pace.
- Relying on technology, using computer programs to tailor curriculum sequencing, pacing, and presentation to students' unique needs, interests, and abilities as learners.
- Tailoring the curriculum and instruction to students' individual needs and interests as learners.
- Using knowledge of students' capabilities and curiosities to determine the pace, style, and content of curriculum for each individual student.
- Partnering with students who have an increased ownership of their education to design learning experiences that suit students' individual interests, skills, and aspirations.
- Organising activities that include questions that students see as important to their lives," suggesting students have choice and volition in the questions they pursue within personalized learning environments.

(Thai et al., 2022) (Netcoh, 2017)

5.1.23 Research-based learning:

In this pedagogic principle, teaching practices include the following:

- Designing activities for students that include:
  - Posing their own research questions with their own hypotheses
  - Inquiring into them systematically
  - Collecting data
  - Analysing their findings
  - Sharing or presenting their research before a real audience
- Reinforcing concepts throughout subsequent inquiry lessons.

(Bjørkvold & Ryen, 2021) (Akerson, Carter, Pongsanon, & Nargund-Joshi, 2019)

5.1.24 Self-regulated learning:

In this pedagogic principle, teaching practices include the following:

- Diagnosing students' learning needs
- Formulating learning goals
- Identifying human and material resources for learning
- Choosing and implementing appropriate learning strategies
- Evaluating students' learning outcomes

- Providing smart learning environments that provided a mechanism for selecting or defining goals to developed skills, improve performance, or defining activities to be achieved in a learning process
- Providing a smart learning environment to provide a mechanism for planning activities before performing on them.
- Providing a smart learning environment to monitor the time spent on learning, assessment, or planning.
- Providing self-assessment, games, and reflective quizzes.
- Using a tool that provides a mechanism to compare learner's performance with their classmates.
- Using interactivity tools to resend the information to the learners about their learning progress and performances
- Creating routines and participation structure
- Positioning all members as learners
- Illuminating connection between strategic action and outcomes
- Providing iterative cycles of learning and long-term learning activities
- Giving appropriately challenging tasks
- Taking learners' heterogeneous characteristics into consideration, including their: level of ability; affective factors (e.g., emotions); interests and needs; and learning engagement
- Providing a personalised learning experience
- Making learning more convenient for learners
- Providing suitable and personalised learning contents
- Creating a personalised profile on learners' learning records
- Providing assessment based on learners' learning profiles
- Making use of learning analytics driven educational technologies
- Enabling easy access to and user-friendly operation of the systems by users
- Allowing access to learning materials anytime anywhere.

(So et al., 2019) (Gambo & Shakir, 2021) (Callan, Longhurst, Ariotti, & Bundock, 2021) (Li & Wong, 2021)

5.1.25 Question-based learning:

In this pedagogic principle, teaching practices include the following:

- Designing activities for students that include:
  - Using open-ended questions beginning with what, why, or how to:
  - Interpreting, analysing, evaluating, making decisions, and explaining information based on reasoning
  - Making Inferences
  - Recognising assumptions
  - Making deductions
  - Interpreting data
  - Evaluating arguments

5.2 Relating teaching practices to the pedagogic principles

The forms of teaching practices in the literature are concerned with five separate categories:

1. Integrating technology (e.g., information processing tools, monitors tools)
2. Designing activities (e.g., connect to big ideas, test ideas, construct a prototype)
3. Integrating affective components (e.g., use of emotions as positive feedback, reflect on feelings)
4. Including external stakeholders (e.g., collaborating with community members, visiting factories)
5. Including cultural component (e.g., consider students' cultural experiences, considering students' differences in culture)

All of the 25 PPs are expected to include all five categories. However, after analysing the literature, it was found that some were mandatory and others were optional. For example:

- In design-based thinking and learning, most of the five categories were included, except for the cultural component.
- In feedback-based learning, only the design component was included.

Table 4 shows the mandatory and optional categories related to each pedagogic principle.

Table 4: Relationship of Pedagogic Principles to Teaching Practices

	Teaching Practices				
	Technology	Design Activities	Affective component	External Stakeholder	Cultural component
Pedagogic Principles					
Design-based/Design thinking learning	■	■	■	■	□
Problem-based learning	□	■	□	□	□
STEM toys learning	□	■	□	□	□
Group learning	□	■	□	□	□
Multimedia learning	■	■	■	□	□
Reflective learning	□	■	□	□	□
Collaborative game-design learning	■	■	■	□	□
Engineering design learning	□	■	□	□	□
Exploratory learning	■	■	■	□	□
Simulative-based learning	■	■	□	□	□
Inquiry-based learning	□	■	■	□	□

	Teaching Practices				
	Technology	Design Activities	Affective component	External Stakeholder	Cultural component
Pedagogic Principles					
Experiential learning	□	■	■	■	□
Feedback-based learning	□	■	□	□	□
Inclusive learning	□	■	■	□	■
Service learning	□	■	■	■	□
Learning by modelling	■	■	□	□	□
Contextual learning	□	■	□	□	□
Digital game-based learning	■	■	□	□	□
Personalised learning	■	■	■	□	□
Intercultural learning	□	■	■	□	■
Mobile or location game-based learning	■	■	□	■	□
Research-based learning	□	■	□	□	□
Question-based learning	□	■	□	□	□
Self-Regulated learning	■	■	■	□	□
Story-based learning	■	■	□	□	□

Key	
■ Mandatory practice	□ Optional practice

6. Phase 3: Instructional approaches and outcomes

6.1 Instructional approaches and outcomes related to each of the pedagogic principles

The third phase of the literature review identified, for each of the pedagogic principles, the instructional approaches and outcomes that were described in the studies. In the following sub-sections, for each pedagogic principle, instructional approaches are listed in the first table. The instructional approaches are further analysed into those considered ‘high level’ and those considered ‘low level’. Below the details of instructional approaches, the learning outcomes are listed for that particular pedagogic principle. The study sources are shown below each list of details of instructional approaches.

6.1.1 Design-based learning:

High Level	Low Level
• Acts as a coach, enabling the student to make the transition from a passive to an active learner. • Gives students materials and resources that: a. involves hands-on techniques, tools, and materials for prototyping or testing. b. involves minds-on tools and materials for design documentation and visualization during the empathizing, ideating, or defining phases. • Groups students in: a. A social environment that is student-centred, fostering a sense of responsibility in students whenever they perform tasks individually or in a small group. b. A social interaction that should enable co-creation where the student can communicate and collaborate with peers and even with stakeholders.	• Gives students open-ended activities with enough flexibility for learning. The activities are: a. authentic (real-life scenarios) for positioning the design challenge and arriving at a solution. b. should be multidisciplinary, enabling students to learn and connect multidisciplinary knowledge and skills. c. should involve the design process/skills, enabling students to acquire new knowledge and skills.

High Level	Low Level
• Creates a climate in which mistakes and failures are accepted to trigger curiosity in students. • Regulates the amount of support so that students feel independent about their learning • Shows interest in students' achievements (e.g., their design ideas, designs created, and progress in projects). • Helps students draw links between their tasks and the design challenge. • Moderates peer feedback moments, to enable students to listen and accept peer critique and feedback. • Provides emotional regulation support for children, especially during iterations. • Creates a comfortable atmosphere within groups. • Cultivates students' sense of responsibility and encourage them to volunteer to offer help to peers. • Guides the apprentice by modelling the reasoning thinking as expert engineers perform the problem analysis in a task • Provokes students with questions. • Models the inquiry thinking • Encourages the reflection process and have students explore their reasoning modes • Supports students to build knowledge in a discipline and develop gradually self-directness and process-oriented instruction. • Coaches on task, process, and self • Challenges students by asking questions • Scaffolds by using of rubrics, hands-outs, and worksheets • Gives just-in-time teaching or lecture-by-demand strategy • Acts as consultant	
Outcomes: Students are able to:	
- Produce creative products - Be mindfulness of the process - Make impact on other people - Think critically thinking - Solve problems	

High Level	Low Level
- Communicate - Collaborate	
(Zhang et al., 2020) (Gómez Puente et al., 2013)	

6.1.2 Problem-based learning:

High Level	Low Level
• Guides rather than conveys information • Facilitates the group's work and internal communication • Distributes worksheets, leads discussions, or help students determine how to search necessary information. • Provides verbal support and ask questions to advance observation, comparison, and the interpretation of data, as well as the deduction and verification of hypotheses and arguments. • Offers guidance to keep the investigative process going in a positive learning direction. • Engages students by presenting the problem. • Explains the roles • Determines what information students already know, what information they need to know, and how best to acquire this information.	• Asks students to analyse their options and decide on an action or a decision. • Asks students to debrief by discussing not only the content they have learned and how it may be useful in new situations but also the processes involved in solving the problem
Outcomes: Students are able to:	
- Be mindful of the process - Make impact on other people - Develop the 21st Century skills - Solve problems - Gain problem solving skills - Acquire digital equity - Acquire mental wellness	
(De Graaff & Kolmos, 2003) (Merritt, Lee, Rillero, & Kinach, 2017)	

6.1.3 STEM toys:

High Level	Low Level

• Proposes ill-structured problems by creating situations
• Proposes ill-structured problems through the creation of situations and guides the students to construct their own problems step by step.
• Refers to the card records of the students' written or drawn solutions in
	• Asks students to:
	  ○ Generate and plan design ideas to build artefacts such as tower
	  ○ Build prototypes successfully for proof of design idea
	  ○ Build the artefact collaboratively with peers

High Level	Low Level
order to understand their individual science performance, problem-solving ability, and the ability to employ effective strategies • Helps students in this process by guiding them through specific steps to clearly understand the key points of the problems • Observes and intervenes to improve students' thinking • Monitors the students to be able to help them. • Involves in the children's game, in order to guide, reinforce and deepen them and then connect previous experiences or create new ones, which are interconnected with the specific goals of a structured activity or a developmental activity plan • Creates activities that match students' level of abilities, create scenarios, socialize, reflect, undertake roles, improvise, have fun, learn, explore, experiment and through these activities comprehensively evolve.	○ Observe how peers create prototypes ○ Observe how peers create sketches to plan for design of the artefact ○ Work with the team to design and build a functional artefact ○ Unpack requirements and constraints via oral discussion. ○ Start to construct an artifact. ○ Test and modify their solutions. ○ Exchange their ideas with other students, prompting them to also express themselves. ○ Choose what kind of play/activity they want to do, what objects to choose, with whom and for as long as they want within the rules of class and the schedule in or outside school, at home or elsewhere.

Outcomes: Students are able to:		
- Complete games - Acquire mechanical learning - Be creative - Apply inquisitive thinking - Apply inventiveness - Work in teams - Experiment	- Imagine - Think collaboratively - Have empathy - Listen - Dialogue - Expressing emotions/opinions/ideas - Interrogate information	- Connect concepts - Integrate concepts - Critique ideas - Use social conversation - Use social understanding
(Zhou et al., 2017) (Y. Li, Huang, Jiang, & Chang, 2016) (Komis et al., 2021)		

6.1.4 Group learning:

High Level	Low Level
• Fosters positive student interaction • Diagnoses the progress of the group and intervenes when necessary • Provides adequate teacher guidance. • Identifies problems in time and do not intervene adequately • Stimulates elaborate explanations (e.g., explaining a concept by giving	

High Level	Low Level
arguments instead of merely providing the correct answer) • Offers compliments and support to groups of students • Composing the collaborating groups and preparing them for the collaborative task. • Acts as a reference or a role model for students by demonstrating how to interact with group members • Stimulates students to explain their ideas to each other and to ask follow-up questions that deepen the group discussion	
Outcomes: Students are able to:	
- Gain social skills	
(van Leeuwen & Janssen, 2019)	

6.1.5 Multimedia learning:

High Level	Low Level
• Triggers, maintains, energizes, or revitalize individual engagement in the learning process.	• Provides activities that target: ○ selecting related words and images for transmitting to working memory ○ organizing selected information to build a cognitive structure in working memory ○ integrating cognitive structures with learners and with prior knowledge that comes from long-term memory
Outcomes: Students are able to:	
- Learn independently - Get engaged in the learning process	
(J. Li, Antonenko, & Wang, 2019) (Coskun & Cagiltay, 2022)	

6.1.6 Reflective learning:

High Level	Low Level
	• Provides activities for giving and receiving feedback • Provides activities for considering and acknowledging students' own learning progress and achievements • Provides activities for critical thinking on an existing technology or a societal issue

High Level	Low Level
	• Provides activities for reflecting on ideation and making process. • Provides activities for reflecting on challenges faced when generating and elaborating ideas with teammates • Provides activities for reflection on students' own as well as others' design or making processes • Provides activities for presenting students' work, sharing ideas with other teams and finding out what they think is considered as important as reflecting on your own design practice • Provides activities for reflecting on their learning process and learning gains, either by reflecting on their metacognition (e.g., how to achieve predefined learning goals) or on their learning progress in acquiring a new skill (e.g., operating laser cutter, 3D printer) • Provides activities for examining and reflecting on students' own progression in learning when figuring out how to solve a problem or change perspective when using a science model. • Provides activities for revisiting students' project and reflecting on the reason behind a technical breakdown that caused an issue • Provides activities for reflecting about the impact of existing technologies on lives and society at large • Provides activities concerned with introspection and self-awareness about one's mental states and emotions (e.g., reflecting on self-image or on feelings of frustration when stuck) activities involve exploration and offer an opportunity for self- evaluation where students learn by trial or error, which can evoke strong emotions (e.g., when faced with failure or challenging situation). • Provides activities for qualitative reflections on learning where students can record a video describing these moments and explore strategies to get ''unstuck''

High Level	Low Level
	• Provides activities for the exploration of students' own emotions when concerned about their self-image in front of their peers when their design does not work properly or integrating identity exploration into design activities with graduate students who are trained to become educators.
Outcomes: Students are able to:	
- Meditate on how new knowledge has been acquired - Analyse which new cognitive and emotional skills were revealed and used to manage their emotions, - Enhance their holistic development - Get engaged in the learning process - Connect to real life	
(Baykal, Van Mechelen, Wagner, & Eriksson, 2021)	

6.1.7 Collaborative game-design learning:

High Level	Low Level
• **Provides support in the "Pre-Game" by:** a. Game play training: Gameplay demonstrations and practice b. Lecturing: Curriculum content and game content • **Provides support in the "Game" by:** a. Scaffolding: Scaffolding content and problem-solving (Doing: High Level) b. Managing the classroom: Giving instructions, timekeeping, seating arrangements, and keeping students on task (Doing: High Level) c. Providing technical support: Hardware, software, and internet • **Provides support in "Post-Game" by:** a. Debriefing: Discussion and reflection	• Gives handouts: Guides, questions, and problems to be solved
Outcomes: Students are able to:	
- Practice multimodal knowledge (Orienting, interpreting, concretizing, and expanding knowledge) - Share knowledge - Improve practice - Participate in socio-digital tasks	

- Share epistemic objects and artifacts - Apply collective learning - Connect to real life
Instructional Approach: (Bado, 2022)

6.1.8 Engineering design learning:

High Level	Low Level
• Provides direct instructions (PowerPoint presentations and Blackboard) and brainstorming activities.	• Provides different kinds of activities that include: ○ defining the problem, planning possible solutions, choosing the possible solution, designating, testing, redesigning, and communicating ○ planning and reflecting ○ analysing, problem-solving, and creating solutions to problems ○ identifying criteria, generating ideas, and evaluating ○ constructing, testing, redesigning, and reviewing ○ investigating possible solutions, creating, testing, analysing, and optimising ○ improving models ○ developing a plan ○ articulating multiple solutions, evaluating, selecting solutions, retelling the performance of the solution, analysing solutions, and improving ○ identifying and investigating the problem, drawing/sketching possible ideas, choosing the best possible solutions, designing, testing, evaluating, and communicating ○ brainstorming, experimenting, designing, building, redesigning/testing ○ Observing, generating questions, conducting investigations, analysing, and reflecting ○ identifying problems, gathering information, modelling, and analysing potential solutions, prototyping, testing, and

High Level	Low Level
	analysing prototype performance ○ designing invention, testing design, achieving the functionality of the invention, and collaborating ○ building contrasting cases, asking, imagining, planning, creating, and improving ○ brainstorming ○ explaining the need, characterizing the need, generating concepts, selecting a concept, embodying the concept, testing and evaluating, finalizing and sharing the design, reflecting on the design process ○ carrying out investigations ○ quantifying the need, engineering the concept, embodying the concept, implementing the design, and finalizing the design. • Provides different kinds of activities such as writing activities (workbooks, design sketches, recommendations, data tables), reading activities (reading paragraphs), inquiry-based activities (paper-based information sources, internet-based information sources), laboratory activities (experiments and observations), simulations activities (Google Sketch up, SEED, WISE, WPBD program), play-based learning activities (Toys activities), outdoor learning activities (outdoor observation), and trial and error activities (randomised activities, LEGO). • Provides activities that imply a picture in which students convey their design solutions. • Provides activities that involve building a two- or three-dimensional design product. • Provides activities that involve experimenting outcomes of the product

High Level	Low Level
	• Provides activities that involve an iterative process following the analysis of the test results.
Outcomes: Students are able to:	
- Build a growth mindset - comprehend life science knowledge - Understand the problem-solving process. - Have collective cognitive responsibility	
(Winarno et al., 2020) (Arık & Topçu, 2022)	

6.1.9 Exploratory learning:

High Level	Low Level
• Instructs to investigate the place as archaeologists or crime detectives, organising a display with found objects from the place, then arranging, and photographing them.	• Provides activities for working with difference and repetition as a creative method to fold, unfold, and actualise/materialise the subject of learning, which creates new ideas and questions. • Provides activities for choosing a place that the student had a personal relation to and investigating it visually through drawing, photographing, collecting found objects, observing, and writing about the place. • Provides activities for training the effects of different exploratory tools, including their own body's movements in and between various environments and visual art materials. • Provides activities for investigating the selected place physically and materially on location using exploratory questions. • Provides activities for analysing and locating discourses, as in ways of looking at the place, and then challenging the dominant ways of seeing the place by creating antitype or atypical images of it, challenging dominant ways of seeing. • Provides activities for presented students' visual and material explorations in a digital portfolio. • Provides activities for folding, unfolding, and differentiating for making connections.

Outcomes: Students are able to:
- Think creatively - Solve problems
(Hellman & Lind, 2021)

6.1.10 Simlative-based learning:

High Level	Low Level
• Introduces a virtual reality • Gives an orientation about the lesson • Trains the students to provide the appropriate feedback	• Provides activities and presentations Plan • Provides educational games, field trips, and role-play Plan
Outcomes: Students are able to:	
- Connect real-life phenomena and the underlying science - investigate causal relationships and scientific questions - Gain conceptual understanding - Think creatively - Solve problems	
(Pellas, Mystakidis, & Kazanidis, 2021	

6.1.11 Inquiry-based learning:

High Level	Low Level
• Focuses on thinking skills • Promotes a culture of inquiry • Guides inquiry discourse • Makes students familiar with the nature of science • Provides information on the research topic • Focuses on conceptual understanding • Bridges the gap between high and low achievers • Organises student learning in groups • Focuses on collaboration processes	
Outcomes: Students are able to:	
- Gain understanding - Construct knowledge - Think creatively - Solve problems	
(Dobber, Zwart, Tanis, & van Oers, 2017)	

6.1.12 Experiential learning:

High Level	Low Level
• Provides some supplementary learning materials • Prompts the teams to accomplish the learning tasks based on their learning portfolio • Encourages children to explain their thoughts and actions … and offer explanations that give insights into their developing thinking • Provides introduction to each lesson • Opens questions and prompts for students to review prior learning • Provides direct instruction to clarify emerging misconceptions • Evaluates students' capacity to link conceptually to their content and ensures that how concepts are represented or may be interpreted by students, minimises the chance of misconceptions. • Facilitates simulations in the same way they facilitate experiments with physical equipment, and not assume they are standalone resources	
Outcomes: Students are able to:	
- Have disaster education abilities - Think critically - Gain real-life experiences - Solve problems	
(Cheng et al., 2019) (Falloon, 2019)	

6.1.13 Feedback-based learning:

High Level	Low Level
• Provides feedback that can be aimed at the self, task, process, and regulation levels. Feedback that is aimed at the level of self does not relate to the task performed but instead relates to characteristics of the learner. • Provides feedback for praising the students, for example, “You are a fantastic student!” • Provides feedback for praising the students at the task level performs a corrective function. • Provides feedback for praising the students at the process level that	

High Level	Low Level
addresses the process that was followed to complete the task. • Provides feedback for regulation level that is related to students' self-regulation • Intervenes—provides feedback—when there is a misunderstanding • Gives encouraging feedback to their pupils, and close collaboration between schools and homes is expected • Gives realistic and process-targeted feedback that may help to strengthen a pupil's feelings of competence in the learning process. • Motivates and engages students in the face of growing learning demands. • Gives little feedback to promote self-directed learning, but instead answer students' questions. • Acts as directive or facilitative. • Provides directive feedback to tell the student what needs to be revised and how. • Provides facilitative feedback with suggestions that students can use in their own revision of their work • Focuses on feedback related to the task • Focuses on feedback related to social learning • Prompts evaluation and reflection by students • Gives specific and clear feedback • Provides feedback that can be focused on student planning • Provides feedback that focuses on goal-directedness • Provides positive feedback • Provides criticism in a positive way • Enhances student self-confidence through feedback • Activates students to work and think • Provides feedback with clear directions that includes hints or suggestions • Answers questions and gives information • Provides feedback that stimulates and challenges students • Provides assistance while searching for solutions	

High Level	Low Level
• Coaches and guides students • Provides feedback that is tuned to individual students • Assesses student prior knowledge and needs first • Checks students work • Creates a good relationship with students • Provides feedback that can be focused on keeping order and rules • Makes sure students can proceed after giving them feedback	
Outcomes: Students are able to:	
- Improve their work - Be prepared for next times - Deconstruct feedback - Feel ownership of their work - Get engaged in tasks - Gain Knowledge - Get engaged in cognitive and motor skills outcomes	
(Van der Kleij, Feskens, & Eggen, 2015) (Kuusimäki, Uusitalo, & Tirri, 2021) (Wang, Matsumura, & Correnti, 2017) (van den Bergh, Ros, & Beijaard, 2013)	

6.1.14 Inclusive learning:

High Level	Low Level
• Deals with diversity in the classroom • Promotes aspects of assessment for learning (i.e., formative assessment), learners taking more responsibility for their own learning, “genuine” learner voice, strong links with the community, and curricular flexibility. • Encourages a growth mindset among learners and understand that individual circumstances can require additional support • Monitors learner progress, develops close teacher-learner relationships, promotes positive teacher perceptions of learners, and employs fair disciplinary policies. • Includes self- and peer assessment • Uses heterogeneous grouping, a system of flexible and well-considered pupil grouping. • Develops a culture of collaborative problem solving	• Asks learners to work together in small learning groups, helping each other to carry out individual and group tasks” • Asks learners to identify the issue, discuss all possible solutions, screen solutions, and choose and evaluate the solution

High Level	Low Level
• Provides formative feedback, peer learning, and peer assessment • Determines learners' progress	
Outcomes: Students are able to:	
- Participate in the organisation - Plan of school activities - Plan of training - Work collaboratively	
(Kefallinou et al., 2020) (Finkelstein et al., 2021)	

6.1.15 Service learning:

High Level	Low Level
• Encourages students to build "flexible, adaptive, and active" networks for learning that promote a view of education that positions the student as an "active participant". This may include services in schools, social initiatives, public institutions, non-profit organisations, or facilities for the disabled. • Promotes understanding of diversity and mutual respect among all participants in a community and include both 'service' and 'learning' elements • Assists others, builds relationships with the invisible and voiceless, heightens awareness of diversity and difference, is able to better understand the realities of culturally and linguistically diverse children • Gives more instructions at the beginning of the course and then increasingly withdraw from this instructive role to promote autonomous learning on the part of the students during the service experience.	• Asks students to work in teams on real-world problems.
Outcomes: Students are able to:	
- Gain social skills - Develop their attitudes and behaviors that contribute to environmental consciousness and action - Learn deeply	
(Gartland, 2021) (Resch & Schrittesser, 2021)	

6.1.16 Learning by modelling:

High Level	Low Level

• Collaborate with students to brainstorm situations to record.
• Coordinates the discussion, manages activities, and plans the sessions
• Provides primary guideline for making a model and to consider its purpose.
• Highlights that they can use more than one model for the same thing because different models can be used to address different specific interests or questions about the referent.
• Highlights that a scientific model can change and be replaced by one that is better for answering questions.
• Scaffolds learners in constructing scientific model using applications that are:
    ○ easy for students to get started building simple models, so that they stay motivated to learn the tool
    ○ supports diverse populations of learners building models in a variety of domains and grow with them as they develop expertise.
• Involves students in inquiry
• Involves students in modelling
• Uses the model for presenting information so that students can gain a deeper understanding.
• Uses the model for explaining something
• Uses the model in such a manner that the students can understand easily. There should not be too much information on the model, and yet it still should be accurate.
• Uses models that are close enough so that if the student were to see the real thing, they would be able to identify it based on the model.
	• Asks students to watch a video presentation and imitates the behaviour modelled in the video at a later occasion. The video presentation includes definite behaviours which can be modelled by peers, siblings, or adults, in an endeavour to acquire new behaviour or modify current ones.
	• Asks students to role-play a behaviour
	• Asks a comprehension question at the end of each video to ensure that students paid attention to the video and understood the material.

Outcomes: Students are able to:
- Understand concepts - transfer and extend concepts and problem-solving skills to new problem- solving situations - Achieve more learning goals
(Haydon et al., 2017) (Roldán-álvarez, Martín, & Haya, 2021) (Crawford & Cullin, 2004) (Alhuzimi, 2020)

6.1.17 Contextual learning:

High Level	Low Level

• Collaborates with students
• Provides high levels of activity in lessons to connect to real world contexts
• Guides students undergo learning
• Uses teaching aids and provides authentic and challenging tasks for the students in order to increase their attention in class and directly increase their scientific attitude.
• Train multiple intelligences, by asking analytical questions, solving problems logically, or plan an experiment to prove something
• Acts as mentors or facilitators in guiding students to become more intelligent, creative, innovative
• Uses the following learning strategies:
  ○ inquiry learning
  ○ problem-based learning
  ○ cooperative learning
  ○ project-based learning
  ○ authentic assessment
• Promotes self-regulated learning and addresses student diversity when teaching
• Evaluates students by means of their performance on tasks that are representative of activities done in relevant, real- life settings, often associated with future careers.
• Uses a portfolio, which is "a purposeful and representative collection of student work that conveys a story of progress, achievement and/or effort"
• Understands and responds to individual student's interests, strengths, experiences, and needs
	• Asks students to:
	  ○ Ask questions
	  ○ Inquire
	  ○ Communicate with the community
	  ○ Modelling
	  ○ Reflect
	  ○ Do actual research
	• Gives students either a real or simulated problem and must use critical thinking skills to solve it Ideally, they will need to draw information from a variety of disciplines. Problems that have some personal relevance to the students are often good choices because they encourage strong participation, learning, and perseverance.
	• Asks students to work together in small groups and focus on achieving a common goal through collaboration and with mutual respect. Each student within the group is viewed as making a significant contribution to the goal.
	• Asks students to work independently or collaboratively on projects of personal interest. There is an emphasis on constructing realistic and valuable work products. When these projects benefit others, and have wider social relevance, they are often described as service learning.

High Level	Low Level
• Focuses on student understanding and use of scientific knowledge, ideas, and inquiry process • Guides students in active and extended scientific inquiry • Provides opportunities for scientific discussion and debate among students • Assess students continuously • Shares responsibility for learning with students • Supports a classroom community with cooperation, shared responsibility, and respect • Treats students as collaborators in the learning process • Collaborates with students by sharing decision making with them and respecting the decisions their students made, which empowered their students and promoted autonomous learning. • Asks students to work together to assist each other's learning and monitor each other's progress and products • Ensures that students learn in an active, hands-on fashion and discover knowledge through their own initiatives • Discourages rote learning in students and foster inquiry, often using Socratic questioning to stimulate higher-order thinking and problem solving when investigating natural phenomena	
Outcomes: Students are able to:	
- Gain Understanding - Comprehend the meaning of the learning content - Be motivated	
(Dewi & Primayana, 2019) (Suryawati & Osman, 2018) (Glynn & Winter, 2004)	

6.1.18 Digital game-based learning:

High Level	Low Level
• **Provides support in the "Pre-Game" by:** a. Game play training: Gameplay demonstrations and practice b. Lecturing: Curriculum content and game content • **Provides support in the "Game" by:**	• Gives handouts: Guides, questions, and problems to be solved

High Level	Low Level
a. Scaffolding: Scaffolding content and problem-solving b. Managing the classroom: Giving instructions, timekeeping, seating arrangements, and keeping students on task c. Providing technical support: Hardware, software, and internet • **Provides support in "Post-Game" by:** a. Debriefing: Discussion and reflection	
Outcomes: Students are able to:	
- Think creatively - Solve problems	
(Bado, 2022)	

6.1.19 Story-based learning:

High Level	Low Level
• Reads the story using the images via picture book or bring images from the Internet web search. • While reading the story, the teacher makes a different voice to represent a different character from the story and uses TPR (Total Physical Response) to act. • Introduces new vocabulary and a review. • Confirms the list of vocabulary in one round. A keyword is decided and written on the blackboard. • Puts students get into pairs • Scaffolds learning to guide practices of creativity strategies and dispositions • Encourages goal setting • Gives constructive feedback and verbal encouragement for performance • Gives hands-on activity using a worksheet • Wraps up • Encourages students to praise their friends and thank each other.	• Asks the students what morals they learned from the story and what they felt was impressive in the story. • Asks students to recall the new vocabulary they heard in the story. • Asks students about the characters they liked in the story. (The discussion time is to encourage students to participate speaking in English)
Outcomes: Students are able to:	
- Think creatively - Solve problems	
(Bidari, 2019) (Yeh et al., 2022)	

6.1.20 Inter-cultural learning:

<table>
<tr><th>High Level</th><th>Low Level</th></tr>
<tr><td>

Activates prior knowledge
Handles errors constructively
Treats students with warmth, respect, and humour
Provides clear rules and routines
Stimulates discussions of different cultural conceptions
Encourages perspective taking
Raises awareness of the dynamic nature of culture
Encourages tolerance and respect
Encourages critical scrutiny of prejudices
Takes into consideration students' own experiences
Encourages tolerance and respect
Encourages critical scrutiny of prejudices
Enhances students' feelings of autonomy, competence, and social-relatedness
Employs a preventive approach to classroom management
Supports reflection on cultural diversity
Support students' self-determination by showing warmth, respect, and humour
Handles errors constructively (

</td><td>

Provides activities for students to explore and share their cultural differences through the web platform
Provides activities for students to raise questions
Provides activities for students to assess their final explanations against accurate explanations/models.
Provides activities for students to collaboratively open discussions through the web platform
Provides activities for students to work collaboratively with one another to explore concepts through hands-on activities
Provides activities for students to redefine their explanations collaboratively based on scaffolding/lesson materials provided by the class teacher
Provides activities for students to explain and share their geographical/cultural differences through the web platform.
Provides activities for students from different countries to interact with each other through Skype-mediated video conferencing and through viewing and commenting on each other’s learning artefacts posted on the project’s online platform.
Provides activities for students to use the video conferencing sessions to engaged students from different countries in conversation about matters related to the science topic that both groups were studying at the same time in the school term.

</td></tr>
<tr><td colspan="2">Outcomes: Students are able to:</td></tr>
<tr><td colspan="2">- Share narrative culture</td></tr>
<tr><td colspan="2">(Vieluf & Göbel, 2019) (Chu, Martin, & Park, 2019)</td></tr>
</table>

6.1.21 Mobile/location game-based learning:

High Level	Low Level
• Provides tasks that are highly student-centred, inquiry-based and collaborative in nature. • Shows students scientific experiments in school - which they frequently filmed using their mobile devices - and were then tasked with devising and undertaking a similar but different experiment at home with the help of their parents, again incorporating the mobile device • Interacts for motivation and control • Guides reflection • Engages learners in reflective data collection for exploring the environment. • Scaffolds learners • Challenges learners • Employs the acquired knowledge for problem solving, and actively construct knowledge. • Engages learners in making reflections and improvements. • Provides activities related to authentic places • Provides activities that students use to recall their knowledge and build stronger connections between the learning content and the targeted objects • Provides collaborative learning tasks • Provides activities that target the exploration of an environment via collecting data, interpreting the data, and making reflections accordingly. • Provides activities that engage students in understanding the observed phenomena via their own efforts to explore the environment • Provides personalized m-learning guidance to individual learners, especially novices or those learners with little (basic) previous knowledge. • Engages students in free exploration in the learning environment. • Provides a context-based dialogue approach for situating students in an authentic learning environment to seek	• Asks students to use the mobile device as a hub to collect, store, edit and analyse data, before sharing it with their peers and teachers. • Asks students to use e-Books, prepared by the teachers • Asks learners to use mobile technology for improving that interaction in learning scenarios by providing various communication facilities. • Provides activities that ask students to use problem-based mobile learning system to help the students collect the required data in field observation activities to improve their question-raising performance. • Provides activities that include a developed concept map integrated mobile learning approach to help students organize what they observed in the field and the content learned from the textbook. • Provides activities that integrate WebQuest and mobile learning strategy, which engage students in a science inquiry field trip for learning and experiencing resource recycling and classification. • Provides activities that engage learners in real-world contexts using mobile devices with access to digital systems for supplemental resources, assessment, guidance or tasks, which could be prepared by the teacher or generated by themselves

High Level	Low Level
appropriate resources for gaining knowledge based on their needs. • Provides a learning support system for guiding students to learn based on the predetermined learning path to maximize their learning outcomes. • Provides a mobile interactive teaching feedback system to support learners with online problem-based asynchronous discussion. • Provides a location-based system that assisted students in observing and constructing knowledge at their own learning pace on an ecological field trip.	
Outcomes: Students are able to:	
- Gain knowledge and skills - Acquire more subject knowledge - Have more interest in learning	
(Burden et al., 2019) (Chung et al., 2019)	

6.1.22 Personalised-based learning:

High Level	Low Level
• Applies a more collaborative relationship with students for sharing responsibility for decision-making within the learning environment • Provides students with choice in the classroom to increase their motivation, engagement, and performance • Gives students organizational choice (i.e., choice in learning environment through co- creation of classroom rules and due dates), procedural choice (i.e., choice in how learning is presented), and cognitive choice (i.e., freedom for students to argue their own points and choice in how they solve problems), (i.e., ways to solve problems), pace (i.e., pace and order of work), format (i.e., how work is presented), topic (i.e., what is studied), and mobility (i.e., working individually or in groups). • Offers students individualized support and guidance during this	

High Level	Low Level
planning process. Once students completed their learning plans, they were provided the freedom to direct their own learning and decide how they want to carry out their projects. • Spends time checking in with individual students, monitors their progress, and provides suggestions for how they could advance their projects. • Involves in students' work as long as it was to help them with the projects they originally chose.	
Outcomes: Students are able to:	
Gain interest and self-confidence	
(Netcoh, 2017)	

6.1.23 Research-based learning:

High Level	Low Level
• Engages students in discussions of their investigations. • Debriefs lessons with a concluding discussion that engage students in thinking about how and what they did in their investigation was similar to what scientists did. • Through discussions, the teacher leads them to think about the data, about observations and inferences, and about how scientists created an understanding from these investigations. • Uses explicit-reflective instruction to improve understandings of the process • Uses explicit- reflective instruction, including observation and inference charts to debrief students' lessons • Leads students to conceptualise scientific creativity by noticing that they are creating an understanding • Directs students to think about various aspects present in the inquiry • Enables students to contextualize instruction into content that students will learn in their classrooms, in this case literacy content. • Reads each aspect and definition from the poster, and talk about the terms	• Asks students to discuss their ideas • Asks students to think about observations in terms of senses, and then the kinds of meanings that they could make from those observations as inferences. • Asks questions to embed students in the teaching content • Asks students to discuss the aspects they noted (with examples) that were present in their inquiry • Ask students to note that as they are creating designs for what contributes to something spinning, they are creating an understanding for what initiates an item to spin (and to spin the longest, for example) • Asks students to make observations of their designs and inferences • Asks students to make records of their science content knowledge as well as their aspect knowledge on worksheets or in notebooks. • Asks students to think about aspects as they conduct their investigations • Uses the poster to ask the students to reflect on their investigation as the teacher draws students' attention to

High Level	Low Level
• Uses think-aloud strategy to model ways to think • Uses questions phrased in ways such that they draw attention to • Draws students' attention to the fact that all students in their group have different knowledge bases they bring to the discussion, and therefore their viewpoints about the investigations may be slightly different. • Helps students understand the importance of evidence, the role of observation and inference as their ideas develop through investigations. • Uses an observation and inference chart that students can use in many different investigations. • Helps students see that they need to collect, organize, and analyse data in order to make scientific claims • Draws students' attention to the importance of collecting and representing these data so they can make better inferences. • Uses explicit and reflective instruction to direct students to notice that they are being scientifically creative in designing, carrying out, recording, and interpreting the data that then influences how they design their roller coasters • Uses hands-on investigations • Motivates students to raise questions, collect data, and make observations and inferences of phenomena. • Uses guided inquiries to help students conceptualize how to design and carry out an investigation by planning the investigation along with them. • Facilitates class discussion surrounding what the students already know about what may influence their inquiry designs. • Discusses with the students what they know about scientific investigations. • Draws students' attention to the data through questioning.	the aspects before and after a hands-on investigation. • Provides students with writing prompts to encourage them to reflect on their content knowledge as well as their understandings. • Asks students to write, using prompts • Asks students to record data as the teacher points out the importance of collecting empirical evidence in the development of scientific understandings. • Asks students to record observations and inferences of phenomena on a chart or in their notebooks. These observations and inferences can be reported to the class for discussion. • Asks students to use charts, graphs, and methods of classifying data to represent their scientific observations • Provide students with activities that engage them in a variety of inquiries from guided (mostly teacher-led) to open (mostly student-led) as they are exploring science • Uses poster to hold a discussion and have students elaborate on how they were scientifically creative in designing the investigation and in interpreting evidence
Outcomes: Students are able to:	
– Connect to the real-world – Choose	

High Level	Low Level
– Be responsible – Think critically – Be autonomous – Be more engaged in learning – Comprehend knowledge – Understand the problem-solving process	
(Akerson et al., 2019)	

6.1.24 Self-regulated learning:

High Level	Low Level
• Uses a mechanism to see if a student is moving towards achieving a set goal. • Provides an evaluation of learners' activities or progress of learning progress. • Monitors and measures time spent on learning, assessment, or planning. • Provides visualization to support self-regulation learning strategies. This show student can use a progress bar or chat to see the learning process's progress and outcomes. • Supports self-regulated learning using solutions to the current problem, personalized messages, or correction. • Provides recommendation that can be skill-based, strategies or widgets to help learners' skills development • Supports learners' help-seeking. These include discussion forums, learning agents, or peer learning. • Measures the learner's opinion on whether the functionalities provided are ease to use and meet their learning need • Evaluates learners' satisfaction. This is the degree to how the functionalities meet learner's learning needs and expectations • Fosters adaptive student–teacher relationships • Develops students' help-seeking and help giving skills • Uses explicit instruction	

High Level	Low Level
• Models self-regulated learning skills • Provides effective feedback • Uses prompts and cues to increase strategic thinking and action and elicit metacognition • Provides activities for self-assessment and self-reflection • Provides worksheets • Encourages Peer co-learning • Facilitates learners to develop personalised learning objectives • Enables learners to have control over the learning process • Enhance computer literacy of learners • Provides personalised guidance for learners • Provides real-time feedback and support	
Outcomes: Students are able to:	
- Learn independently - Get engaged in the learning process	
(Gambo & Shakir, 2021) (Callan et al., 2021) (Li & Wong, 2021)	

6.1.25 Question-based learning:

High Level	Low Level

• Provides guiding questions for students to actively explore the required knowledge to solve the problems.
• Poses questions to serve a variety of purposes, such as managing the classroom, reinforcing a fact or concept, stimulating thinking, arousing interest, and helping students develop a particular mind-set
• Poses questions that act as instructional cues or stimuli that convey to students the content elements to be learned and directions for what they are to do and how they are to do it.
• Stimulates, guides, and assesses the science process skills and mastery of knowledge of the students.
• Uses questions to:
  ○ give the instruction
  ○ discover something unknown by the teacher
	• Provides activities to encourage students conduct investigations and learn more independently

<table>
<tr><th>High Level</th><th>Low Level</th></tr>
<tr><td>

determine whether the students know something
develop students' thinking skills
motivate students to learn
provide training and practice
help students organize the material
help students interpret the material
emphasize the things that are important
show the relationship such as causality
know the interests of students
develop an appreciation to students
provide an assessment
give practical expression
reveal mental processes
indicate approval and disapproval
report
diagnose
evaluate
get attention

Provides instruction, develops students thinking skills, motivates students to learn, develops critical thinking skills and inquiry attitudes, and encourages students to hunt their own knowledge
Begins with questions that aim to motivate and focus students’ attention on the concept to be studied.
Directs the student investigation to the inquiry process.

</td><td></td></tr>
<tr><td colspan="2">Outcomes: Students are able to:</td></tr>
<tr><td colspan="2">
- Develop creativity
- Learn flexibly
- Inquiry and discover
- Learn from errors and failures
- Open to novelty
</td></tr>
<tr><td colspan="2">(Adnyana & Citrawathi, 2017) (Citrawathi & Adnyana, 2018)</td></tr>
</table>

6.2 Overview of the pedagogic outcomes

The pedagogic outcomes were divided into three types:

1. Application (e.g., Produce creative products, Solve problems, Communicate, Collaborate, Complete games)
2. Knowledge gain and processing (e.g., Think critically, Gain problem solving skills, Imagine)

3. Change in attitude (e.g., Be mindful of the process, Learn independently, Feel ownership of their work, Be motivated)

All of the 25 pedagogic principles are expected to be included in the three types of pedagogic outcomes: 1) application; 2) knowledge gain and processing; and 3) change in attitude. However, with respect to the 25 pedagogic principles, the literature focused on certain types of outcomes and did not involve others. Table 5 provides an overview of the relationships found between pedagogic principles and pedagogic outcomes. The numbers of outcomes identified were used to categorise four levels of outcome: none; low; medium; and high. For example:

- In design-based thinking and learning, there was: 1) high focus on application; 2) low focus on knowledge gain and processing; and 3) low focus on change in attitude.
- In feedback-based learning, there was: 1) medium focus on application; 2) low focus on knowledge gain and processing; and 3) low focus on change in attitude.
- In the multimedia learning, there was: 1) low focus on application; 2) no focus on knowledge gain and processing; and 3) low focus on change in attitude.

Table 5: Relationship of Pedagogic Principles to Pedagogic Outcomes shown in the reviewed Literature

Pedagogic Principles	Pedagogic Outcomes		
	Application	**Knowledge Gain & Processing**	**Change in attitude**
Design-based/Design thinking learning	▲	▼	▼
Problem-based learning	▼	●	▼
STEM toys learning	▲	●	▼
Group learning	O	▼	O
Multimedia learning	▼	O	▼
Reflective learning	▼	O	▼
Collaborative game-design learning	▲	O	O
Engineering design learning	▼	▼	▼
Exploratory learning	▼	▼	O
Simulative-based learning	▼	▼	O
Inquiry-based learning	▼	▼	O
Experiential learning	▼	▼	▼
Feedback-based learning	●	▼	▼
Inclusive learning	●	O	O
Service learning	O	▼	▼
Learning by modelling	▼	▼	O
Contextual learning	O	▼	▼
Digital game-based learning	▼	▼	O
Personalised learning	O	O	▼
Intercultural learning	▼	O	O
Mobile or location game-based learning	O	▼	▼
Research-based learning	▼	●	▼
Question-based learning	▼	▼	▼
Self-regulated Learning	▼	O	▼
Story-based learning	▼	▼	O

Key			
NONE = 0 **Symbol** = (O)	**LOW** = less than or equal to 3 outcomes **Symbol** = (▼)	**MEDIUM** = from 4 to 6 outcomes **Symbol** = (●)	**HIGH** = more than or equal to 7 outcomes **Symbol** = (▲)

6.3 Relating instructional approaches to the pedagogic principles

Instructional approaches in the literature were identified through two different categories:

- High-level approaches (e.g., Fosters positive student interaction, Diagnoses the progress)
- Low-level approaches (e.g., Gives handouts, Provides activities)

All of the 25 PPs are expected to include the two levels of approaches. However, after analysing the literature, it was found that: 1) some included both levels; 2) some included either one or the other level; and 3) some excluded one of the levels. In addition, it was found that in each level, there was either: 1) high focus; 2) low focus; 3) medium focus; or 4) no focus.

For example:

- In design-based thinking and learning, the high-level approaches were highly focused, more than the low-level approaches, which were considered low in focus.
- In feedback-based learning, only the design component was included.

The relationship between pedagogic principles, and the levels of approach and their levels of focus, is shown in Table 6.

Table 6: Relationship of Pedagogic Principles to Instructional Approaches

	Instructional Approaches	
	High-Level	**Low-Level**
Pedagogic Principles		
Design-based/Design thinking learning	▲	▼
Problem-based learning	▲	▼
STEM toys learning	▲	▲
Group learning	▲	O
Multimedia learning	▼	▼
Reflective learning	▼	▲
Collaborative game-design learning	●	▼
Engineering design learning	▼	▲
Exploratory learning	▼	▲
Simulative-based learning	▼	▼
Inquiry-based learning	▲	O
Experiential learning	▲	O
Feedback-based learning	▲	O
Inclusive learning	▲	▼
Service learning	●	▼
Learning by modelling	▲	▼
Contextual learning	▲	▲
Digital game-based learning	▲	▼
Personalised learning	●	O
Intercultural learning	▲	▲

Mobile or location game-based learning	▲	▲
Research-based learning	▲	▲
Question-based learning	▲	▼
Self-regulated learning	▲	O
Story-based learning	▲	▼

Key			
NONE = 0 **Symbol** = (O)	**LOW** = less than or equal to 3 approaches **Symbol** = (▼)	**MEDIUM** = from 4 to 6 approaches **Symbol** = (●)	**HIGH** = more than or equal to 7 approaches **Symbol** = (▲)

7. An overview framework

In Figure 4, an overview framework relates the twenty-five pedagogic principles to:

1. The eight pedagogic objectives (numbered from 1 to 8 in green)
2. The three pedagogic outcomes (numbered from 1 to 3 in blue)
3. The five teachers' practices (numbered from 1 to 5 in orange)
4. The two levels of instructional approaches (numbered from 1 to 2 in yellow)

Each pedagogic principle is shown on the left, and the cells to the right of it show the eight pedagogic objectives, the three pedagogic outcomes, the five teachers' practices, and the two instructional approaches.

An important note to consider when reading this framework:

- If the cell is empty, that means that this cell is optional.
- If the cell includes a number that means that this cell is mandatory.
- The number in each coloured cell corresponds to the category to which it belongs.

For example:

- In Design-based/Design thinking learning:
  - Objectives shown are:
    - 1, 3, 4, and 6, which correspond to solve problems, collaborate, interact, and design.
  - Outcomes shown are:
    - 1, 2, and 3, which correspond to application, knowledge gain and processing, and change in attitude.
  - Teaching practices shown are:
    - 1, 2, 3, and 4, which correspond to technology, design activities, affective component, and external stakeholders.
  - Instructional approaches shown are:
    - 1 and 2, which correspond to high-level and low-level instructional approaches.

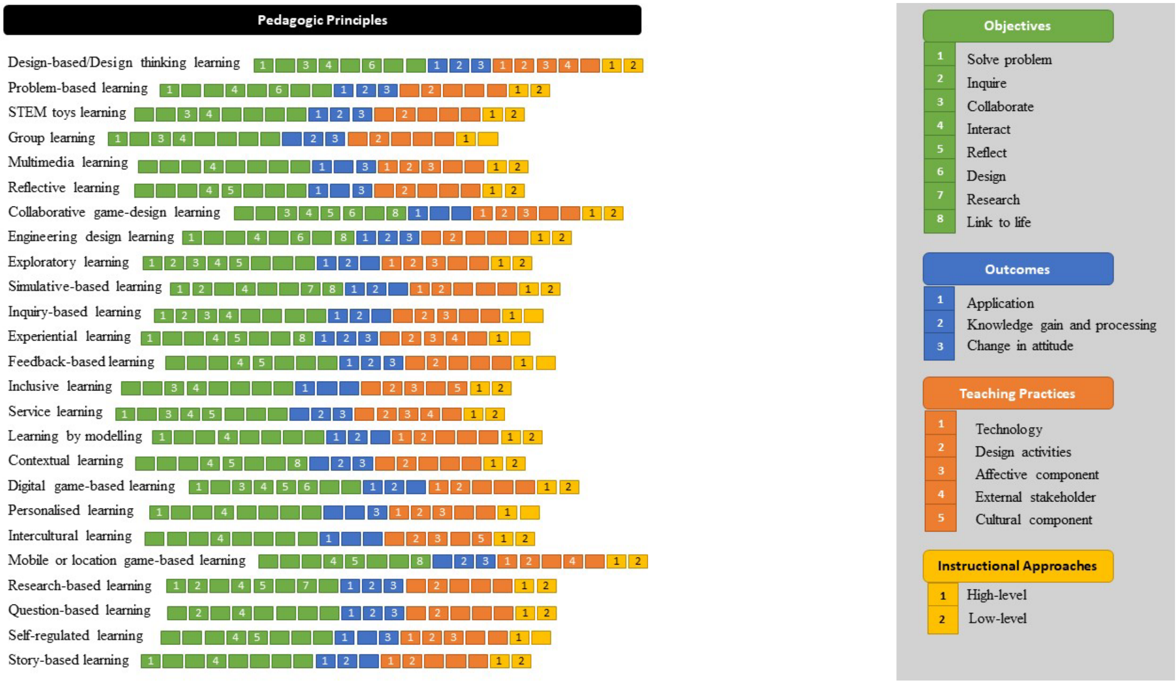

Figure 5: The Overview Framework

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