RbtsInMath: Developing Mathematics Achievement through Using Robotics Applications in Flipped Learning

Project number: 2022-1-PL01-KA220-HED-000086524

Teacher Guide for Applying Flipped Learning in Robotics Practices in Primary Schools

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Chapter 1: Introduction to Digital Pedagogy (Społeczna Akademia Nauk, Paweł Pełczyński, PhD)

Digital pedagogy represents a significant paradigm shift in education, focusing on the integration of technology to transform traditional teaching methods into more dynamic, inclusive, and engaging hands-on activities. At its core, digital pedagogy uses tools such as interactive platforms, robotic kits, and collaborative technologies to foster creativity, critical thinking, and problem-solving skills. This approach not only supports learning, but also prepares students for the challenges and opportunities of a rapidly changing digital world.

Robotics education is an excellent example of the implementation of the principles and applications of digital pedagogy. By combining theoretical concepts with practical activities, robotics enables students to apply knowledge in practical contexts, encouraging innovation and building skills to cope with new situations. This approach promotes active participation in learning and the development of future competencies such as interdisciplinarity and collaboration. This guide will provide guidance on how teachers can implement digital pedagogy, using mathematics education as a practical framework for its implementation.

The importance of digital pedagogy

The importance of digital pedagogy has increased significantly in recent years, which is the result of the dynamic development of technology and changing educational needs. Traditional teaching methods often don't engage students enough, especially in fields like STEM (science, technology, engineering, math), where abstract concepts can seem disconnected from their real-world applications. Technology-driven digital pedagogy allows for a more interactive and engaging approach that effectively combines theory with practice.

For example, as part of robotics education, students can learn the principles of physics or mathematics by designing and programming how robots work. Thanks to this, they gain not only theoretical knowledge, but also the ability to apply it in real situations.

Benefits of digital pedagogy

Digital pedagogy offers a number of significant benefits that significantly affect the quality and efficiency of the teaching process:

a) Combining theory with practice
Robotics education provides an excellent example of how digital pedagogy helps students understand how theoretical principles can be applied to real-world applications. For example, when designing a robot to sort objects by color, students use the principles of optics, programming and algorithmics. This activity not only illustrates the theoretical foundations, but also allows students to solve practical problems in a dynamic way.

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b) Promoting lifelong learning
Digital pedagogy develops skills such as adaptability, flexibility and independent learning. These are key competencies in the knowledge-based economy, where changing technologies require continuous development of one's qualifications. Implementing tools such as Scratch or Python teaches students programming that develops their ability to think critically and analytically. These types of skills remain valid throughout the student's professional life.

c) Strengthening inclusivity
Thanks to digital platforms, education is becoming more accessible and user-friendly for every student, regardless of their needs or limitations. Digital pedagogy enables individualization of teaching, adjusting the pace and level of difficulty to the student's abilities. For students with learning disabilities, visual programming languages such as Blockly are available to eliminate the barriers associated with writing code, allowing learning through interactive experiments. Tools like Google Classroom allow teachers to monitor student progress in real time and tailor materials to their individual needs.

Digital pedagogy in practice

In practice, education with use of digital pedagogy enables students to carry out projects that develop both knowledge and soft skills, such as cooperation, communication and creativity. Implementing digital pedagogy in the classroom can take many forms. Students can work together in teams on robot projects that solve specific problems, such as programming a machine to automate block sorting. Schools with limited access to robotic equipment can use simulators such as TinkerCAD (Fig. 1) to teach programming and design in a virtual environment.

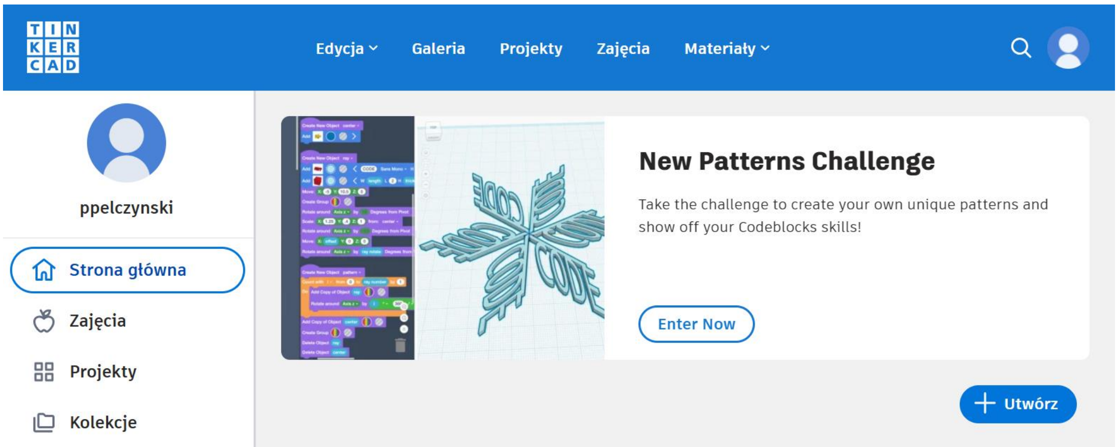

Fig. 1 TinkerCAD main page.

It is no less important to improve teachers' competences in this area. Online training offered by platforms such as Coursera or Khan Academy allows teachers to gain programming and project management skills in the field of robotics. Cooperation with other teachers, e.g. within local educational networks, allows for the exchange of experiences and best practices.

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Explanation and principles

Definition and scope of digital pedagogy

Digital pedagogy is an approach to teaching that integrates digital tools, platforms, and strategies to create more engaging, personalized, and interactive learning experiences. In contrast to traditional teaching models, that often rely on passive content delivery, digital pedagogy emphasizes active participation, collaboration, and critical thinking (Siemens, 2005).

In primary education, digital pedagogy opens up new possibilities for dynamic interaction with teaching material for both students and teachers. For example, in a robot class, students can use online coding platforms to program their robots and then test designs in physical or virtual labs. This approach promotes activity, creativity, and collaboration, which allows for a deeper understanding of the material (Papert, 1980).

Robotics provides an ideal example of digital pedagogy, combining practical knowledge with the use of digital tools to develop key competences of the 21st century (Resnick et al., 2009). With its comprehensive nature, digital pedagogy equips students with the skills they need to navigate an increasingly digital world while developing key cognitive and social competencies.

The most important features of digital pedagogy are:

1. **dynamic learning experiences** - supports interactive and engaging activities that attract students' attention,
2. **personalization** – adapts to the diverse needs of students, ensuring inclusiveness and equality,
3. **scalability** - digital tools can be adapted to different skill levels – from a beginner using visual coding platforms to an advanced one based on Python programming,
4. **active involvement** - encourages students to be creators and problem solvers rather than passive recipients of information,
5. **connection to reality** - robotics tasks often mimic real-world applications, such as designing robots for medical care or environmental monitoring (Eguchi, 2014).

Key principles of digital pedagogy

Digital pedagogy is based on the following four principles, which support interactivity and active learning in dynamic and diverse learning environments.

I Student-centered approach

In a student-centered approach, teachers act as facilitators, supporting students in discovering new concepts. Students are encouraged to actively participate in education, explore the material independently, and experiment (Vygotsky, 1978).

The most important elements of this approach are:

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1. Self-paced learning through digital tools such as coding platforms and online tutorials (Siemens, 2005)
2. creating space for experimentation, e.g. programming robots to perform simple tasks, which develops critical thinking skills,
3. developing self-solving skills that are crucial in today's world.

For example, students may be asked to program a robot to sort objects by size. This task requires analysis, planning, and iterative revisions, while promoting self-reliance and creative thinking.

II Inclusivity

Inclusivity means that every student, regardless of background or ability, can fully participate in the learning process. Digital pedagogy introduces tools and resources that enable all students to actively participate in learning, which is especially important in robotics education (Koehler et al., 2013).

The main features of inclusive digital pedagogy:

1. adaptive tools such as Scratch, which uses drag and drop, or Bee-Bots, which easily introduce younger learners to the world of coding (Resnick et al., 2009),
2. tasks varying the level of difficulty, from simple programming exercises to complex problem-solving challenges,
3. accessibility features such as text-to-speech, adjustable font sizes, and intuitive visual interfaces support students with a variety of learning needs.

For example, in robot programming classes, students with different levels of proficiency can work on the same task but tailored to their abilities – younger children program simple robot movements, while more advanced students integrate sensors to make the robot perform more complex tasks.

III Flexibility

Flexibility means adapting teaching strategies and teaching materials to changing classroom dynamics and individual student needs. Teachers can use data from digital platforms to monitor student progress and identify areas for additional support (Siemens, 2005). Robotics tasks can be modified, introducing new challenges that will engage students and support their development in different areas (Koehler et al., 2013).

IV Technology integration

The integration of technology in education allows for the seamless integration of digital tools into everyday teaching practice. Technology is becoming not only a support for students, but also a tool for developing their creativity, analytical thinking and problem-solving skills (Eguchi, 2014). Platforms such as Google Classroom or Seesaw (Fig. 2) enable improved communication and exchange of resources, which is invaluable in flipped learning.

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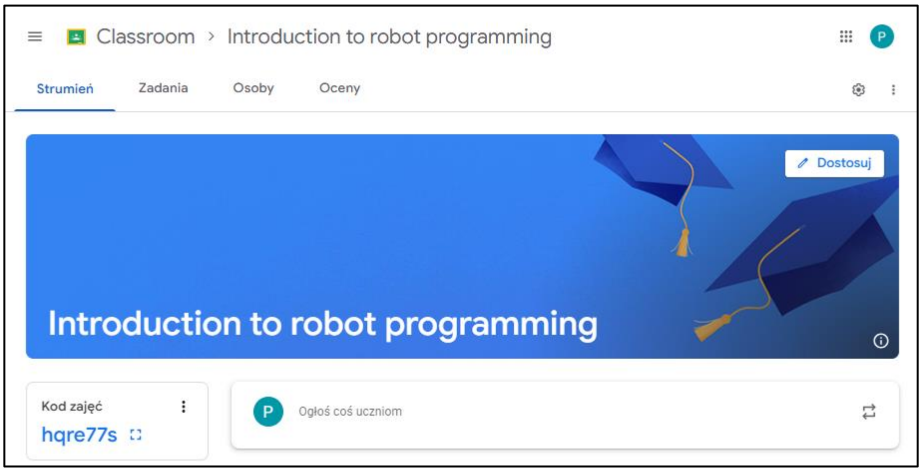

(a)

(b)

Fig. 2 Main pages of learning platforms:9 a) Google Classroom, (b) Seesaw.

Robotic sets like LEGO Spike offer opportunities to put abstract concepts into practice. Coding platforms such as Scratch and Python engage students in computational thinking and creative problem-solving, developing technical skills not only in the context of robotics but also in STEM education in general (Resnick et al., 2009).

3. Link to robotics education

Robotics education provides an excellent context for applying the principles of digital pedagogy. With its features, robotics supports key skills such as computational thinking, creativity, collaboration, and problem-solving.

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a) Computational thinking

Robotics-related tasks teach students to break down problems into smaller pieces, identify patterns, and develop algorithms. As noted by Papert (1980), computational thinking develops problem-solving skills and a creative approach to tasks. For example, programming a robot to navigate a maze requires analyzing key decision points and designing appropriate algorithms, which develops analytical skills and planning skills.

b) Creativity

Designing, building, and programming robots encourages students to think innovatively and explore unique solutions. This approach, as noted by Resnick (Resnick et al., 2009), creates space for creative problem solving in the real world.

c) Troubleshooting

Iterative robot improvement teaches students critical thinking and perseverance, as it often involves testing and correcting errors in the code (Koehler et al., 2013).

Benefits for teachers

The introduction of flipped learning and digital pedagogy into robotics education has numerous benefits for teachers, creating a more dynamic, effective and rewarding learning environment. This approach not only enriches the learning experience of students, but also equips teachers with tools and strategies that optimize their time, develop technical competence, and foster teamwork (Koehler et al., 2013).

Increased student engagement and motivation

Flipped learning and digital pedagogy are transforming the traditional classroom into an active, student-centered environment where students are more engaged and motivated to learn (Hattie, 2009).

1. **Interactive lessons**: The use of robotics kits and programming tools in hands-on activities captures students' attention and arouses their enthusiasm. By providing immediate feedback, robots allow students to see the effects of their work in real time (Resnick et al., 2009).
2. **Self-discovery**: With flipped learning, students have the opportunity to explore robotics topics on their own using digital resources such as video tutorials, development platforms, and interactive simulations. This autonomy develops curiosity and a sense of responsibility for one's own learning process (Siemens, 2005).
3. **Gamification and challenges**: The introduction of gamification elements, such as robotics competitions or competitive tasks, motivates students and develops their love of problem-solving and creativity (Gee, 2003).

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Engaged and motivated students create a more rewarding work environment for teachers, who observe greater participation in classes and better educational outcomes.

Optimize classroom time

One of the key benefits of flipped learning is the ability to effectively use classroom time for more meaningful interactions and activities (Bergmann & Sams, 2012). By assigning introductory materials, such as basic programming tutorials, to students as homework, teachers can devote their classroom time to more advanced and practical activities, such as experimenting with robots or exploring topics (Koehler et al., 2013). Instead of a traditional lecture, teachers can conduct classes in the form of workshops, in which students program robots to perform specific tasks or solve problems inspired by reality, such as simulating rescue operations (Papert, 1980). The increased amount of time allows teachers to provide more personalized support, especially to students who need extra help, while more advanced students may pursue more difficult projects (Koehler et al., 2013). This time optimization not only improves student learning outcomes, but also reduces the workload of teachers during lessons, making them more productive.

Development of teachers' technical competences

Digital pedagogy and robotics education provide teachers with the opportunity to expand their technological and pedagogical competences (AbdulRab, 2023). Teachers gain proficiency in the use of robotic sets (e.g. LEGO Spike, Bee-Bot) and programming platforms (e.g. Scratch, Python), which enriches their didactic repertoire and builds confidence in the integration of technology in teaching (Eguchi, 2014). Introducing strategies such as flipped learning into everyday practice allows teachers to apply innovative methods in a variety of subjects, which supports their professional development (Darling-Hammond, 2000). The regular use of digital tools keeps teachers up to date with technological innovations, which allows them to stay relevant in a dynamically changing educational environment (AbdulRab, 2023). The acquired skills can not only be used in the classroom, but also open up opportunities for teachers to mentor colleagues or participate in educational communities focused on technology.

Opportunities for cooperation and mutual support

Digital pedagogy fosters a culture of collaboration and knowledge sharing among both teachers and students (Fullan, 2013). Robotics projects often require teamwork, which gives teachers the opportunity to support and observe group dynamics as well as build positive relationships in the classroom (Hattie, 2009). Teachers can co-design flipped learning activities, share resources, and solve technological challenges together, creating a supportive professional network (Koehler et al., 2013). Participation in local or global teacher communities, such as LinkedIn groups or educational forums, allows for the exchange of experiences and best practices in teaching robotics (Schmidt, et al. 2023).

Enrich the learning process with student perspectives

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Robotics often triggers creativity and innovation in students, which gives teachers the chance to learn from their pupils. Students can propose non-standard solutions, such as programming a robot to perform artistic activities such as painting, which inspires teachers to experiment further with teaching methods (Papert, 1980).

Tools and resources

Implementing digital pedagogy in robotics education requires a comprehensive set of tools and resources that support interactive teaching, programming, and collaboration. Equipping classrooms with carefully selected robotic kits, software and digital platforms enables teachers to create dynamic, engaging and effective lessons. As Zheng (Zheng, 2018) notes, digital technologies allow for effective personalization of teaching, increasing student engagement and improving educational outcomes.

Robotic Kits

Robotics kits form the foundation of hands-on learning, allowing students to build and program robots while developing key skills such as problem-solving and computational thinking. As Eguchi (Eguchi , 2014) emphasizes, interaction with robotics develops students' competences related to design, coding and logical thinking. The most recommended sets include:

1. **LEGO Mindstorms** - combines intuitive building modules with programming interfaces, teaching students the basics of robotics. It is ideal for younger learners, but scalable for more complex projects (Lixiao, 2013),
2. **LEGO Spike** - a simplified version of LEGO sets (Fig. 3. (a)), adapted to early education, developing creativity and introducing the basics of programming. Spike is particularly useful in learning how to design simple robots with a variety of functions (MTA, 2020),
3. **VEX Robotics** – offers kits to suit different age groups, emphasizing the importance of design, engineering, and coding (Fig. 3.(b)). Especially recommended in teaching advanced STEM content and in competition projects.
4. **Bee-Bots and Blue-Bots**: These simple, programmable robots are excellent for elementary school students, introducing coding concepts in an accessible and fun way. Students can program the robot's movements using intuitive buttons, making them an ideal tool for the little ones (Papadakis, 2022).

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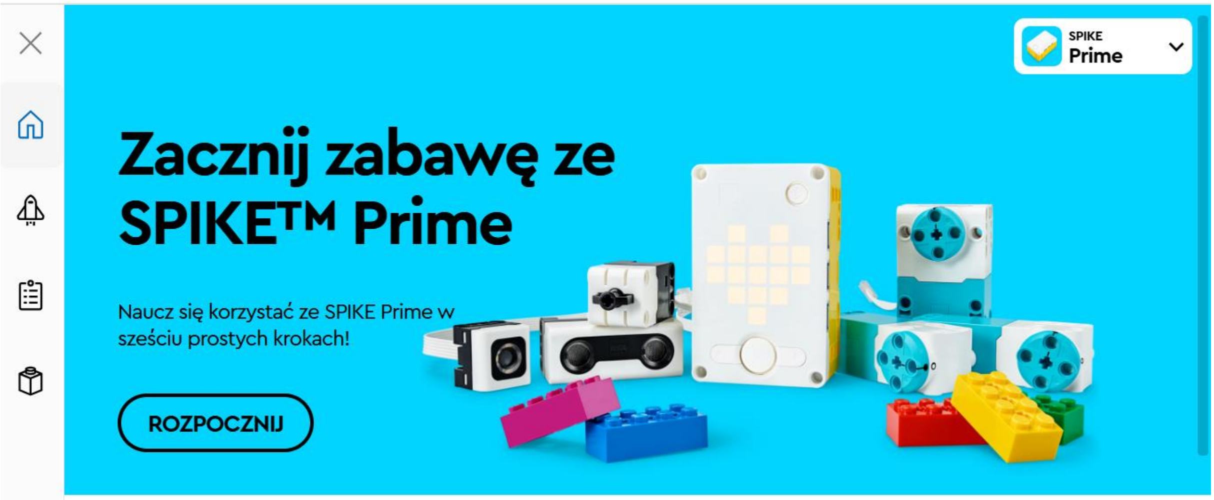

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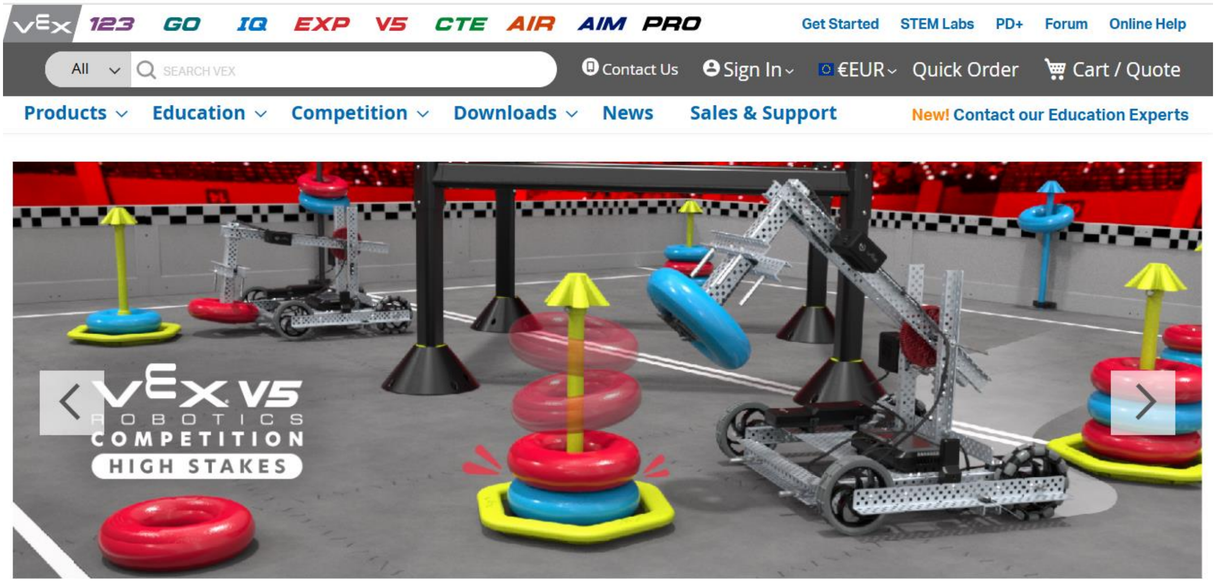

(b)

Fig. 3 (a) LEGO Spike and (b) VEX-Robotics main pages.

The main advantages of robotic kits include adapting to different levels of student proficiency, building engagement through a hands-on approach to learning, and the ability to adapt projects to current learning needs, such as sustainability or automation (Eguchi, 2014).

Robot programming software

Programming is a central component of robotics education, and programming tools make it accessible to students of all ages. The most popular platforms and languages include:

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1. **Scratch** - a blocky programming language designed for beginners. Allows students to create animations, games, and simple programs for robots without the need for text-based languages (Resnick et al., 2009),
2. **Python**: A versatile, text-based programming language used in advanced robotics and real-world applications. Thanks to its simplicity of syntax and high computing power, it is an excellent choice for learning computational thinking (Briggs, 2022),
3. **TinkerCAD:** A tool that combines 3D design with coding, allowing students to simulate electronic circuits and prototype robotic designs (Takáč et al., 2023),
4. **Blockly**: Another block-based platform that simplifies programming while introducing students to basic coding concepts useful in more advanced text-based languages (Google Developers, 2015).

Digital platforms supporting flipped learning

Digital platforms play a key role in delivering flipped learning content, supporting collaboration and classroom management. The most popular platforms of this type include:

1. **Moodle** - a comprehensive learning management system (LMS) that allows teachers to organize lessons, share resources, and monitor student progress (Dougiamas et al., 2003); the Moodle homepage is shown in Fig. 4,
2. **Google Classroom** - a user-friendly platform for sharing teaching materials, collecting student work and conducting discussions. Its integration with other Google tools supports collaborative learning (Google for Education, 2020).

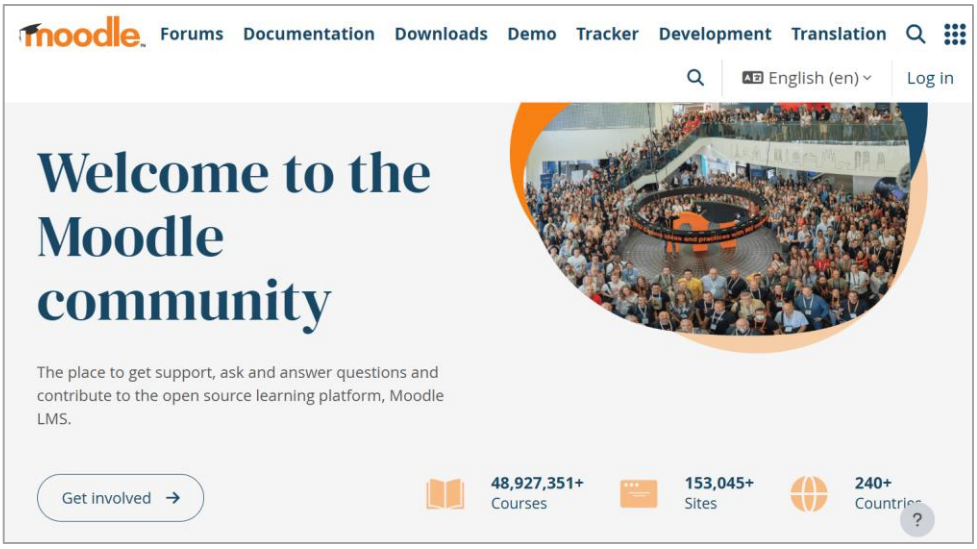

Fig. 4 Moodle main page.

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Strategies for active learning and collaboration

Active learning and collaboration are essential elements in robotics classes that allow students to fully engage in the learning process, develop creativity, problem-solving skills, and collaboration. By using active learning strategies, teamwork and the use of digital tools, teachers can create an environment in which students thrive. This section outlines practical strategies that support the development of problem-solving skills, creativity, and collaboration in robotics learning.

Designing robotic challenges to promote problem-solving

Practical activities form the basis of robotics education, giving students the opportunity to apply the theoretical knowledge they have acquired in practical tasks (Papert, 1980). The following types of activities can be distinguished:

1. **open-ended challenges** - presenting problems without a ready-made solution, such as designing a robot to navigate a maze; such tasks involve critical thinking and creativity (Resnick et al., 2009),
2. **Iterative Design Process** – Encouraging students to test, evaluate, and refine robot designs teaches them perseverance and analytical skills. As Hattie (2009) points out, the process of learning by trial and error develops the ability to solve problems,
3. **Linking to reality** – linking challenges to real-world scenarios, e.g., programming a robot that supports healthcare activities, helps students see the practical application of robotics learning in the real world (Eguchi, 2014).

By designing challenges that require innovation and experimentation, teachers can develop problem-solving skills and keep students actively engaged in learning.

The role of group projects in creating co-innovation

Robotics projects foster collaboration, allowing students to combine their individual skills and perspectives to create innovative solutions (AbdulRab, 2023). Assigning specific roles in groups (e.g., designer, developer, tester) ensures that each team member contributes to the common effort. Role rotation allows all students to develop different skills (Vygotsky, 1978). Setting clear, shared goals that require teamwork, such as building a robot that performs a series of tasks, supports collaboration and student motivation to perform as a team (Hattie, 2009). Creating groups of students with different abilities supports peer learning and promotes inclusivity, which fosters a better understanding of diversity and mutual support (Koehler et al., 2013). Group projects teach students not only to collaborate, but also to communicate and organize work, which is a key skill in today's world (Gee, 2003).

Integrating the session with peer feedback

Feedback from peers helps students learn from each other, improve their projects, and develop critical evaluation skills (AbdulRab, 2023). Using clear criteria to guide feedback sessions, such as the functionality, creativity, and efficiency of robot designs, allows students

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to adapt their work to the requirements (Resnick et al., 2009). Organizing sessions in which students present their projects orally or in writing allows for the exchange of constructive criticism and ideas (Vygotsky, 1978). After each feedback session, it is worth giving students time to reflect on suggestions and make corrections to their projects, which strengthens their ability to improve their work independently (Hattie, 2009). These sessions not only improve the quality of students' work, but also develop their ability to give and receive constructive criticism, which is essential in the process of personal and professional development.

Using gamification to increase engagement

Gamification introduces elements of the game into learning robotics, which increases students' motivation and engagement (Gee, 2003). These can include:

1. **competitions** – organizing robotic challenges, such as obstacle courses or races, allows students to present their projects while also rewarding creativity and innovation (Eguchi, 2014).
2. **achievement badges** - awarding digital or physical badges for achieving specific goals, such as completing a programming task or building a functional prototype, increases motivation and satisfaction (Gee, 2003).
3. **Difficulty levels** - Creating tasks of increasing difficulty, similar to the structure of computer games, keeps students engaged and encourages them to take on more difficult challenges.

Gamification fosters healthy competition, while making learning robotics more enjoyable and rewarding (Takáč et al., 2023).

Using digital tools for brainstorming

Digital tools support collaboration and planning, even in diverse or hybrid learning environments (Fullan, 2013). Platforms like Miro allow students to present their ideas visually, both in the classroom and in remote work. Tools like MindMeister enable students to organize and expand their ideas in a collaborative way. Using platforms like Google Docs allows students to work together on project plans, share code, or document progress. These tools not only foster collaboration but also help students practice digital skills, which are essential in today's world of work (AbdulRab, 2023).

Conclusion

The implementation of digital pedagogy in mathematics education represents a groundbreaking step towards equipping students with the skills and mindset necessary for success in the 21st century. This approach combines innovative teaching strategies with practical educational tools, creating an environment where students thrive as active participants in their learning journey. By integrating flipped learning and fostering collaboration, teachers can revolutionize the way robotics is taught in primary schools, opening the door to student's full potential (Papert, 1980; Siemens, 2005).

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Digital pedagogy shifts the emphasis from traditional teaching methods to a dynamic, student-centered approach to learning. Through robotics education, students gain hands-on experience with technology while developing key skills such as computational thinking, creativity, and problem-solving (Hattie, 2009). Robotics also emphasizes inclusivity, ensuring access to valuable learning experiences for all students, regardless of their background or ability (Eguchi, 2014).

With tools such as robotics kits, coding software, and digital platforms, digital pedagogy enables the seamless integration of theoretical knowledge with practical application, making learning engaging and relevant to contemporary educational needs (Resnick et al., 2009).

Flipped learning plays a key role in digital pedagogy, optimizing classroom time and fostering active student engagement. Through this approach, students explore the basic concepts of robotics on their own, allowing them to approach classroom activities with confidence and curiosity. Teachers can dedicate classroom time to team projects, hands-on challenges, and support that targets specific student needs, maximizing the impact of face-to-face interactions. Lesson materials, tailored to the individual needs of students, support a diverse pace of learning, promoting autonomy and inclusion. Flipped learning fits perfectly into constructivist theories that emphasize active knowledge construction and collaboration in problem-solving, making it an ideal approach for teaching robotics.

Successful implementation of digital pedagogy requires teachers to adopt innovative approaches and experiment with a variety of strategies. From gamified challenges to collaborative brainstorming with digital tools, the possibilities are endless. Teachers should start small by introducing simple tools such as shared digital whiteboards or robotics kits for beginners. They should then gradually expand their skills by exploring advanced development platforms and engaging in professional development (Darling-Hammond, 2000). They should also collaborate with colleagues in the industry, sharing ideas, resources and best practices in teaching robotics. By taking these steps, teachers can create a dynamic learning environment that not only inspires students but also helps them build confidence in using technology (Siemens, 2005).

Digital pedagogy in mathematics education offers great opportunities for both students and teachers. It creates classrooms that become centers of creativity, collaboration, and innovation. By using flipped learning and digital tools, teachers can prepare students for a technology-dominated future while developing life skills. The educational process starts with curiosity and a desire to explore — so let's boldly enter the world of digital pedagogy and inspire our students to do the same.

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Chapter 2: TEACHING PRINCIPLES AND METHODS IN THE DIGITAL AGE (CANAKKALE ONSEKIZ MART UNIVERSITESI, Hasan Arslan, PhD)

Introduction

Education has been the most fundamental element in both the personal development of individuals and the shaping of social life in every period of human history. Many thinkers such as Socrates, Aristotle, and Plato have emphasized the necessity of creating educational programs to reach virtuous people by expressing education as the highest virtue. Education is organized as formal education in order to support the mental, social-emotional, and psychomotor developments of individuals in a balanced manner within the framework of the principle of integrity. Formal education is usually shaped in school systems within a certain plan and includes various elements such as goals, content, educational status (teaching methods, etc.), measurement-evaluation, and qualified educators. These elements change shape according to the characteristics of the age and differ in line with the expectations of individuals and societies from education. When we consider the age we are in, technological developments, and digital transformations; it is a must for individuals and educational institutions to keep up with and follow this change. The harmony of the distant, general, and specific goals of educational programs with the teaching methods and techniques used in the teaching processes increases the effectiveness of learning. In this context, it is a necessity of our age that educational programs that include various pedagogical approaches and learning theories and take individual differences into account provide a multidimensional learning environment.

Traditional and Digital Teaching Methods

In order to understand teaching methods, it is necessary to understand learning theories related to learning.

Learning Theories: Educational institutions aim to ensure that individuals learn in a planned and systematic manner. In this context, answers should be sought to critical questions such as “What has been learned?”, “What should be learned?”, “How is it learned?” The concept of learning has been tried to be explained by many learning theories, primarily under the control of behaviorist and cognitive theorists (Akman, 2018). These theories actually seek an answer to the question of “how can education be best done?” While some of these theories agree on the answer to this question, others are based on completely different paradigms. The most accepted classification of learning theories is behaviorist, cognitive, affective, social, brain-based and constructivist theory.

Behaviorists explain learning in terms of environmental events and believe that mental processes are not necessary to explain the acquisition, maintenance and generalization of behavior (Schunk, 2012). Behaviorist theories state that learning is based on a connection

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between stimulus and response and that behavior is acquired through reinforcement (Akkaya, 2015). It is not possible to talk about a single approach in the behaviorist learning approach. Because there are different theories based on behaviorism such as classical conditioning, correlationism, and operant conditioning. What is important in behaviorist approaches is observable and measurable behaviors. The learning principles of behaviorist theories are reinforcement, repetition, and motivation (Özden, 2011).

Cognitive learning theories; focus on mental processes in the learning process in which the learner understands his/her environment. According to cognitivists, learning is a much more complex event than the stimulus-response relationship and learning cannot be observed directly. Learning can be explained from a cognitive perspective as the development and change in the mental structures of a person. Affective learning theory; is based on the necessity of considering the affective field, where only the cognitive field is not sufficient, and attaches importance to mental and affective development and change. Affective theory is more concerned with the results of learning than its nature. For these developments and changes, values and moral development are emphasized together with the concepts of healthy self, self-actualization and being fully functional. (Akkaya, 2015; Akman, 2018). In short; behaviorist theories are interested in the practical results of learning; cognitive theories are interested in the mental results; affective theories are interested in the emotional results of learning such as self and moral development (Akkaya, 2015).

Social learning theory states that individuals observe other people in their environment and display behaviors that are beneficial to them (Bandura, 1991). In social learning, the focus is not on experience as in conditioning, but on observation. As is known, social learning theory does not only mean learning through observation, or repeating behavior with reinforcement. Observation also has the function of informing the individual. Behaviors taken as models, which are an important element in the social learning process, can be stored and changed. Observed behaviors coded in the individual's memory can be recalled when necessary. (Bal, 2020).

Brain-Based Learning Theory, which examines learning from a neurophysiological perspective, explains the learning process as biochemical and electrochemical changes. According to this theory, during the learning process, connections are established between brain cells. New learning means new connections between cells (Kaya, 2012). There are certain methods and techniques of learning in brain-based learning, and learning occurs through reasoning. Brain-based learning theory is similar to other learning theories with many of its features. For example, there are elements such as the constructivist approach, such as learners learning by doing and experiencing and being involved in the decision-making process. It is also similar to the theory of multiple intelligences in some respects (Akman, 2018).

Traditional Teaching Methods

Based on learning theories, we can group teaching methods as traditional and contemporary teaching methods. Traditional teaching methods have shaped pedagogical practices for centuries and have formed the basis of learning processes. Traditional teaching methods are based on behaviorist learning theories, they treat learning as a product rather than a process,

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and they do not take individual differences into account. Traditional teaching methods are not learner-centered, but are based on the transfer of basic knowledge and skills, where the teacher is at the center and seen as a source of information, and where discipline and order in the classroom are at the forefront, and they are generally methods that include methods such as narration and question-answer, and are not open to change and development. Traditional teaching methods can be listed as plain narration, question-answer, writing on the board, writing in a notebook, and repetition-based exercises. In the plain narration method, the teacher transfers information systematically, and students passively listen to what is conveyed and take notes. The plain narration method can be used effectively in knowledge-based disciplines such as Mathematics. The question-answer method is when the teacher asks questions to students about what they convey; it activates the flow of the lesson, and can help students focus their attention. Writing on the board method; It is the teacher's transfer of the important points of the lesson to the board by emphasizing them and allows students to follow the subject visually. Repetition and practice; It is based on students' strengthening their memory by repeating the information many times in order to ensure the permanence of the information (Jeffries et al., 2003; Prince et al., 2006). Traditional teaching methods have advantages such as being able to transfer information to a large number of students at the same time and being effective in teaching basic knowledge sets in disciplines such as history, mathematics and grammar. However, traditional teaching methods have many disadvantages. These are (Jeffries et al., 2003; Prince et al., 2006): - They may be inadequate in supporting problem solving, critical thinking, and creative thinking skills.

Students are passive, their active participation in the learning process is limited.

They are inadequate in developing 21st century skills.

- Students are pushed into a competitive learning environment and cooperation between students is weak.
- They may reduce students' motivation and interest in learning.
- They ignore individual differences.
- They do not take students' learning styles into account, they offer a single type of learning environment that is not suitable for their learning speed.
- Since a single type of teaching method is taken into account, they may cause students who need different learning methods to fall behind.
- They are inadequate in providing the versatility and flexibility required by the modern education approach.
- The feedback mechanism is limited due to not including process-oriented measurements and seeing learning as a product. This prevents students' progress from being effectively monitored and the learning process from being individualized, and may cause the quality of learning to decrease.
- In order to achieve permanent learning through active participation in education, traditional teaching methods must be blended with learner-centered, technology-based contemporary teaching methods.

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Digital Teaching Methods

In our age, the unstoppable advancement of technology has transformed education as well as many areas of daily life and science. In this context, digital teaching methods are becoming an indispensable element of education and offer endless opportunities for improving learning experiences and designing qualified learning environments. In order to meet the needs of today's learners in learner-centered contemporary education approaches, the integration of digital tools into education is not a choice but a necessity. Especially during the COVID-19 pandemic period all over the world, the transition to digital education has accelerated and the importance of teaching methods with advantages such as spatial/temporal flexibility and accessibility has been revealed. Digital teaching methods cover various technologies such as interactive boards, online learning platforms, e-learning platforms, virtual reality (VR), virtual classrooms and artificial intelligence (AI) supported educational applications.

It is a necessity to integrate digital teaching methods into education due to reasons such as its adaptability and accessibility; offering personalized/individualized learning opportunities; increasing the learner's participation in the process by providing motivation (Chapman & Rich, 2018; Scarpiello, 2021). Digital platforms provide learners with access to teaching materials without any time and space limitations, providing students who are far away or who do not have the opportunity to benefit sufficiently from educational services with the opportunity to learn independently of geographical restrictions. Digital teaching methods provide personalized learning experiences with adaptable learning platforms, evaluate the strengths and weaknesses of learners, take into account individual differences and offer personalized content suitable for individual learning needs (Scarpiello, 2021). One of the most important advantages of digital learning methods is that feedback mechanisms are fast and effective. In this way, students can correct their mistakes by receiving instant feedback and have the opportunity to improve their learning processes. Integrating digital teaching methods into education can be done through simulations, digital educational games, etc. They make learning more enjoyable through interactive tools and increase the student's participation in the active learning process, ensuring effective and permanent learning (Chapman & Rich, 2018). As with every teaching method, digital teaching methods also have limitations/disadvantages. The main ones are; digital divide, educators not having sufficient digital knowledge and skills, learners being exposed to screens too much. Not all students have equal access to the necessary technology and reliable internet connection; This causes digital inequality, which is one of the obstacles to equal opportunities in education. Support can be provided to eliminate this inequality. Sometimes it may not be possible for educators to use digital tools effectively in teaching because they do not have sufficient knowledge/education. Providing professional development programs and in-service trainings to educators to adapt to new technologies will be effective in eliminating this limitation. One of the biggest handicaps of digital teaching tools is that students spend too much time in front of the screen. This situation negatively affects both physical and mental health. For this, the process must be planned very well and parents and students must be made aware of it.

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Pedagogical Models for Online Learning

With the widespread use of technology in education, online learning methods, which are among the digital teaching methods, have become an inseparable part of the teaching process. Online learning is sometimes used alone and sometimes as a complement to face-to-face teaching methods. In this way, learning processes are made more flexible and personalized. When pedagogical models for online learning are examined; constructivism, connectivism and blended learning come to the fore. If we briefly examine these:

Constructivism is based on an understanding that encourages students to actively participate and interact with learning materials, supports students to discover information and create their own meanings, and assumes the responsibility of learning (Piaget, 1972; Vygotsky, 1978). The online learning method supports the constructivist approach by creating learning paths suitable for students' individual speeds with interactive content that enriches the learning process. Virtual collaboration tools, online discussion forums, interactive information sharing and collective learning processes, which are online teaching platforms, offer teaching environments that are compatible with the basic principles of constructivism (Anderson, 2008). Connectivism is one of the prominent pedagogical theories of the digital age and emphasizes that learning is based on a dynamic and continuous interaction rather than a static process in order to keep up with the rapidly changing nature of knowledge (Downes, 2012). Based on individuals learning information through networks, connectivism emphasizes how internet-based technologies such as web browsers, search engines, wikis, online discussion forums and social networks contribute to new ways of learning. Learning does not occur between individuals but within and between networks. In the connectivism model, access to and sharing of information is supported through online learning communities and social media; thanks to these networks, students become continuous learners. This model allows students to collect and synthesize information from different sources and use this information in practice (Downes, 2012; Siemens, 2005).

Blended Learning is an eclectic approach that aims to minimize the disadvantages of online and face-to-face learning methods and bring together the advantages of both. (Çırak Kurt, 2017; Graham, 2006). This approach allows students to have flexible learning experiences and benefit from different learning environments (Garrison & Vaughan, 2008).

Online Learning Methods

Online learning methods can be listed as synchronous, asynchronous, mixed/hybrid (fixed), adaptive, linear, interactive, individual, collaborative, computer managed, computer assisted.

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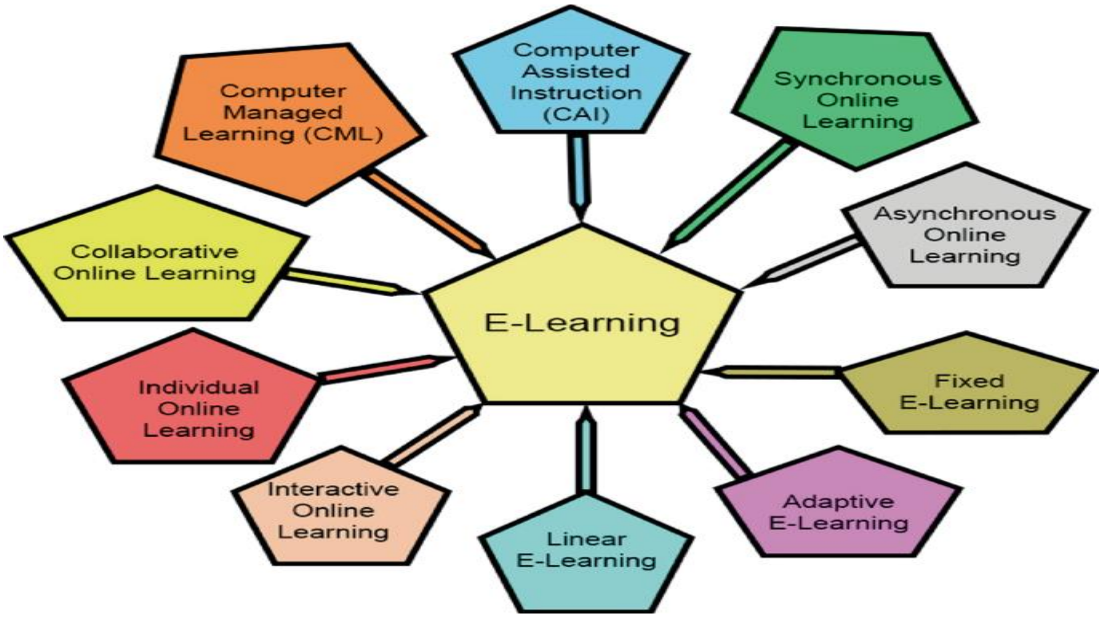

Figure 1. Online Learning Methods

Synchronous online learning is a learning method where students and teachers are online at the same time and simultaneous interactions take place. It provides students with the opportunity to understand the content and group dynamics based on cooperation due to its advantages such as instant feedback-correction, simultaneous discussions, etc. (Hrastinski, 2008).

Asynchronous online learning is an asynchronous learning method that allows students to learn at their own pace and in their own time frame. It is supported by tools such as pre-recorded lessons, online forums, and teaching materials and reading materials uploaded to the system. It provides flexibility as it is independent of time and space, gives students the opportunity to think and analyze in depth, and adapts to individual learning styles (Murphy et al., 2011).

Mixed/hybrid (fixed) learning is a method where both face-to-face and distance education are included in the teaching process (Graham, 2006). Hybrid learning is a learner-centered learning process where classic face-to-face activities are combined with an effective, practical and educational design using recorded and mobile resources as well as printed resources (Jamison et al., 2014). Adaptive learning is an innovative method that is shaped according to the individual interests and needs of students. Technological tools analyze students' performance and redesign learning materials for each student, and appropriate strategies are presented (Hall et al., 2019). This method personalizes the learning process and allows students to focus on their deficiencies.

Linear learning; is a method where each stage is based on previous knowledge and the student progresses sequentially, and there is no two-way communication. Educational materials are sent through tools such as television and radio programs. This method can be used in programs where there is little need for interaction.

Interactive learning; is a method that encourages students to actively interact with educational materials. It is effective in increasing students' motivation and participation

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because it is supported by simulations, interactive videos and educational games (Gee, 2007). Interactive learning methods provide students with experience-based learning environments, allowing them to develop their knowledge and skills, and developing critical thinking skills (Çıtak, Duran Aksoy, 2023).

Individual learning; is a method where students learn on their own in line with their own learning speed and needs, and develops self-regulation and independent study skills (Zimmerman, 2002). Students learn by researching information sources such as online libraries, websites, etc.

Collaborative learning; is a method in which multiple students come together and learn together through active group work and solve problems together. Online platforms allow students to work on joint projects and share information (Dillenbourg, 1999). In collaborative learning, students realize their strengths and weaknesses, and their social communication skills and teamwork abilities develop.

Computer managed learning; is a method in which the computer manages the learning process and monitors/assesses student progress. It progresses through a database, databases contain pieces of information that students will learn, automatic tests and assessment tools monitor students' development and provide feedback when necessary (Anderson, 2008). In this method, there is a two-way relationship between the computer and the student, and the learning process can continue until the specified goals are achieved.

Computer assisted learning; is a method in which computers are used to present teaching materials and support their activities. Education provided through computers establishes a bond between the teacher and the student in the classroom environment, changing the educational process from teacher-centered to student-centered (Batdı & Anıl, 2021). This method provides students with access to information through various digital tools and resources (Jonassen, 1995).

Differentiated Instruction with Digital Tools

Differentiated instruction is a learner-centered approach that aims to meet the individual interests and learning needs of each student and is based on planning the teaching process by taking into account individual learning styles and readiness levels (Hall et al., 2019; Tomlinson, 2001). This type of instruction includes course content and activities adapted to students' interests, readiness levels and learning profiles. Differentiated instruction may require instructional planning at different difficulty levels depending on the abilities of each student. There are six important principles that should be taken into account for the implementation of differentiated instruction (Çam & Acat, 2023):

1. Instruction should be structured around the basic concepts, principles and skills of each subject. What is important in differentiated instruction is learning the basics and important parts of the subject.

2. Flexibility should be provided by taking into account individual differences in the class and these differences should be respected.

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3. Flexible grouping is essential in differentiated instruction. Students work in groups in various ways depending on their individual differences and the type of activity. The size of the groups is arranged according to the number of students with the same learning needs and the level of complexity of the activity to be completed.

4. Students should be given tasks according to their individual differences. Since it is essential to examine the subjects in depth in differentiated instruction, each student is given tasks to the extent that they can handle them and ensured that they overcome them.

5. Differentiated instruction should be open to continuous change.

6. Continuous evaluation should be made in instruction.

Differentiated teaching with digital tools is the application of this method through digital platforms and technologies. By personalizing course content with digital tools, students' academic success, learning levels, and learning motivation can be increased by educators (Anderson, 2008); students' learning can be monitored instantly and incorrect learning can be prevented by providing instant feedback and correction (Means et al., 2010).

For project result preparation, differentiated teaching with digital tools allows for the collection of rich data on student engagement, progress, and areas for improvement. This data can be analyzed to identify trends and patterns that inform more effective instructional practices, contributing to evidence-based outcomes. By incorporating adaptive technologies, educators can create personalized learning paths, which can serve as valuable case studies or pilot results for broader dissemination (Smith et al., 2015).

In terms of project dissemination, digital tools facilitate the creation of interactive reports, presentations, and multimedia content that vividly showcase the effectiveness of differentiated teaching. Platforms such as online learning management systems (LMS) and collaborative digital environments enable seamless sharing of project results with stakeholders, fostering greater transparency and engagement. Additionally, video demonstrations, webinars, and virtual workshops can be employed to reach wider audiences and illustrate best practices (Brown & Green, 2019).

By leveraging digital tools in differentiated teaching, projects can achieve higher levels of scalability and replicability. This approach not only enhances the learning experience for students but also provides valuable insights that can shape future educational initiatives and policies (Reeves, 2020).

How to Implement Differentiated Instruction with Digital Tools?

Differentiated instruction with digital tools can be implemented by teachers combining various strategies and technologies. Some of these are:

A. Learning Management Systems (LMS): They can be defined as software platforms used by educators to manage, distribute and monitor learning materials. Popular LMSs such as Moodle, Blackboard and Google Classroom allow various learning materials such as online courses, educational content, assignments and exams to be organized according to the individual needs of students and to monitor student learning (Watson & Watson, 2007). LMSs

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are tools that facilitate teaching processes for both students and educators (Pina, 2010). LMSs have many advantages such as easy access and flexibility, student tracking and feedback, and interaction and participation with forums / discussion boards / messaging tools (Anderson, 2008; Hrastinski, 2008; Means et al., 2010).

B. Adaptive Learning Software: These are software such as DreamBox and Smart Sparrow that adapt course content according to the learning speed and level of students and support personalization of education (Hall et al., 2019). Adaptive learning software collects data throughout the education process with specially prepared learning programs for the individual and optimizes the educational content with adaptive learning technology. Adaptive learning software allows each individual to receive content that suits their learning outcomes. Just as a navigation application for cars takes the vehicle to the destination in the most efficient way and determines a new route when it goes wrong, adaptive learning software performs the same tasks for students. Some of these software (https://belisoft.com/custom-elearning-development/ai-in-education/adaptive-learning-ai):

- Duolingo; brings together machine learning and adaptive learning in artificial intelligence. This application focuses on language learning through gamification and adaptability.
- Prodigy Math is a gamified software that is based on an adaptive algorithm to provide math learning and can identify student strengths and weaknesses.
- Embibe is a software that combines artificial intelligence and data science to help K-12 students fill in their knowledge gaps and prepare for exams.
- Lexia PowerUP is a software developed to help 6-12th grades increase their reading and writing skills. The software uses tests to guide the student, offers practice tips, and provides audio and text support.

Figure 2. The 8 Best Adaptive Learning Platforms in 2024

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(https://change.walkme.com/adaptive-learning-platforms/)

C. Interactive Educational Tools: These are tools that aim to increase participation by providing students with interactive and fun learning activities (Clark & Mayer, 2023). Some of these tools:

- Kahoot; is a Web 2.0 tool and a platform where online exams, surveys or discussions can be created. With Kahoot, questions prepared by the teacher in advance are displayed on the screen one by one, students mark the answers and collect points via the internet with their mobile devices. When the questions are finished, the names of the students who ranked are shown on the screen. The teacher can also review the result reports and reveal deficiencies (Tetik & Korkmaz, 2018).
- Quizizz; is an easy-to-use platform that helps students have fun while learning and teachers present interactive learning materials in classroom lessons. Users can create quizzes, games and surveys to share with students in the classroom or via distance education (https://support.quizizz.com/hc/en-us/articles/203610052-What-is-Quizizz).
- Nearpod; is a mobile and web application that allows teachers to create and share engaging multimedia presentations with their students. With Nearpod, teachers can easily add interactive features such as quizzes, surveys, and videos to their presentations (https://www.upeducators.com/blog/what-is-nearpod-features-and-uses-in-the-classroom/).

D. Data Analytics and Feedback Systems: Data analytics are systems used to analyze data collected from students' learning processes by digital tools and to optimize educational processes by making this data meaningful (Siemens, 2013). In this way, information is provided about student participation, progress, performance, and other learning criteria. Feedback systems are used to provide instant or periodic feedback to students and teachers using this data (Means et al., 2010).

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Chapter 3: Designing educational math games with robotic toys (Lucian Blaga, PhD, University of Sibiu, Mihăescu Diana, PhD; Bologa Lia, PhD; Bîclea Diana, PhD)

Introduction

Play is a fundamental aspect of early childhood development, serving as a cornerstone for cognitive, emotional, and social growth. Within the realm of education, integrating play into the learning process has shown significant benefits, particularly in mathematics education. The didactic game, as an interactive and enjoyable classroom activity, fosters curiosity and motivates students to explore and understand mathematical concepts. As advancements in technology reshape educational practices, the inclusion of gamification elements and educational robots has emerged as a powerful tool to enhance student engagement and comprehension. This chapter examines the role of educational games and instructional robots in mathematics education, exploring their potential to cultivate essential mathematical skills, foster critical thinking, and prepare students for a technology-driven future. Grounded in the principles of constructivist and dynamic learning theories, it highlights how innovative instructional designs leveraging robotics can transform traditional approaches to mathematics teaching, emphasizing student-centered, experiential learning.

Explanation and principles

Play is crucial for the development of a kid during the preschool years. During this period, they undergo a series of significant transformations at the cognitive, emotional, and social levels. The didactic game is an essential instrument in mathematics education; as a classroom activity, it fosters a pleasant and inspiring atmosphere, igniting curiosity and the pursuit of knowledge. The incorporation of gamification elements through educational robots can significantly improve the teaching process (Tan-I Chen et al., 2023).

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Technological mathematics games can enhance mathematical awareness. A design that facilitates the integration of mathematical concepts can markedly enhance comprehension, retention, and application of acquired knowledge (Moyer-Packenham et al., 2019).

Games are crucial in cultivating the four fundamental competencies (Russo et al., 2021):

a) fluency;
b) comprehension;
c) problem-solving;
d) reasoning.

Studies demonstrate that engaging in mathematical learning via games enhances students' perseverance and fosters deeper, more critical thinking. Enhanced participation in educational activities, prompted by games, is associated with elevated intrinsic motivation and improved comprehension of knowledge applicability (Moon & Ke, 2020). Using games to teach math is an excellent approach to increase student motivation and engagement. Studies demonstrate that game-based learning enhances information retention and fosters the development of crucial abilities, including critical thinking and problem-solving (Wan et al., 2010).

When building an educational game featuring instructional robots, it is crucial to analyse the game's aim, the mathematical abilities it cultivates, and the objectives and anticipated consequences. The game including instructional robots should function as a catalyst for learning mathematics and comprehending mathematical concepts, which are often challenging for children owing to their abstract character.

An efficient instructional design utilising educational robots integrates programming, robotics, and mathematics in a dynamic and engaging manner. The utilisation of educational robots in mathematics classes highlights the enhancement and cultivation of competencies, skills, and dispositions in the subject. They can be utilised in the educational process, beginning with the establishment of mathematical concepts in preschool and progressing through fundamental acquisitions to the development of mathematical notions, which emphasises student-

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centered instruction rather than content-centered, and the cultivation of competencies specific to the discipline of mathematics.

The principles established by Zoltan Dienes underpin the development of mathematical concepts, facilitating the creation of the formative value of logical-mathematical games (Fabian and Kasza, 2022). Zoltan Dienes' ideas of mathematical learning have been implemented in mathematics instruction, establishing a framework for the development of abstract mathematical notions (Sriraman and English, 2005). The implementation of principles proposed by Z. Dienes aids in developing a training model for the cultivation of mathematical concepts, principles that will support the design of activities in the guise of games utilising educational robots:

1. The constructivist principle emphasises the acquisition of knowledge through a logical progression of concepts. Programming the robot facilitates the delineation of steps for addressing a problem or challenging scenario, establishing an initial point and a terminal point, as a consequence of the mathematical framework devised and diverse circumstances;

2. The dynamic principle, the accumulation of experiences with the educational robot, and the execution of actions as a game culminate in the construction of a notion. The move from unstructured to structured play will facilitate comprehension of the specified mathematical subject. Implementing regulations or varying game scenarios provides the flexibility to select alternative pathways yielding identical results;

3. The principle of mathematical variability involves the evolution of abstraction and generalisation in the cultivation of mathematical reasoning. The activities conducted with educational robots are structured as a game, wherein fundamental concepts are elucidated through instances, facilitating the development of a more generalised understanding;

4. The principle of perceptual diversity. The development of mathematical structures in several perceptual modalities. The educational experiences of students and their distinct personalities will result in diverse learning scenarios, enabling them to comprehend mathematical topics in a more enduring manner and to cultivate adaptable mathematical reasoning.

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The learning outcomes in the classroom using educational robots depend on the educational level, subject area, duration of use, type of assessment, and type of robot. (Wang et al., 2023). In the process of conducting the game, there are three factors: a) the students; b) the teacher; c) the technology. Each element contributes to the efficient use of educational robots in math classes, achieving the established goals.

A special role is played by the student who:

- does not limit themselves to contemplating the situation they are in; they reflect on this situation, independently imagine various possible solutions, confront their own opinions with those of their peers, and rectify any potential errors;
- studies the various options that lead to a solution, choosing the most advantageous one and creating new alternative solutions based on it, which he seeks to formulate correctly and coherently;
- has complete freedom in choosing the solution variants - he must justify his choice by showing his colleagues the advantages they present;
- during the game, some mistakes can be made, and the child is helped and guided to correct them on their own or with the support of their peers;
- in the course of the games, the conscious activity of continuous searching and discovering solutions is essential (Mărcuț, 2015).

The benefits of applying educational robots in mathematics are numerous, including:

1. Learning takes place through personal experiences. Students learn by using, building, and experimenting with robots (Chin et al., 2014; Giuseppe & Martina, 2012).
2. Development of critical thinking. Programming robots requires logical thinking, problem-solving, and creativity (Isabelle M. L. et al., 2019).
3. Collaboration and communication. Working in a team on robotic projects improves social and communication skills. (Khanlari, 2016).
4. Increased motivation. Robot activities make learning more fun and engaging (Chin et al., 2014; Konijn & Hoorn, 2020).

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5. Preparation for the future. Develop essential digital skills for today's society, such as programming and computational thinking (Alqahtani et al., 2022).
6. Differentiated learning. All children have access to learning regardless of each child's abilities and capacities (Conchinha et al., 2015, Konijn & Hoorn, 2020).

Benefits for teachers

Creating a gamification activity entails a multifaceted process that encompasses: establishing educational goals, analysing the target group's attributes (interests, knowledge level, preferences), tailoring game mechanics to the group's specifics, and ensuring alignment between learning objectives and the employed game elements (Kim, 2015). Educators can modify the curriculum content to facilitate activities in the form of mathematical educational games, utilising the educational robot as the primary resource. An exercise or problem may be considered a didactic game if (Nour, 2022): a) it fulfills a goal and a pedagogical objective from a mathematical standpoint; b) it incorporates game components to achieve the designated task; c) it employs established game rules that are understood and adhered to by students.

Teachers' pedagogical experiences encompass tactics that integrate educational robots into the teaching-learning-assessment process through the application of diverse instructional methodologies and processes. D. Catlin and M. Blamires (2010) identify 28 distinct methodologies for employing educational robots: catalyst, demonstration, games, presentations, challenges, design, group activities, tasks, problem-solving, conceptualisation, engagement, inductive reasoning, project-based thinking, cooperation, experimentation, connections, provocateur, creative experiences, modeling puzzles, curriculum development, exploration, memorisation, relational approaches, artifacts, deduction, focused tasks, pacification, and transfer.

Educational robots can be utilised throughout the entire educational process: from instruction and learning to assessment. The robot can serve as a significant instrument in the

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implementation of pedagogical approaches and tactics. The primary advantages of utilising educational robots within the teaching framework are (Khanlari, 2016):

a) The customization of learning, enabling educators to design individualised activities at varying degrees of complexity and adapt tasks to meet the specific needs of students. Activities can be modified to suit different developmental stages of youngsters. Diverse educational pathways can be established to inspire and accommodate the interests of children;

b) prompt and accurate feedback allows for the swift rectification of gaps during robotic tasks. Educators can readily intervene for rectification and guidance. This motivates people to persist in their efforts;

c) engaging and enjoyable learning activities, structured as games with educational robots, incentivise children's participation, facilitating knowledge acquisition. This procedure facilitates a more streamlined experience for educators;

d) robots enhance the enjoyment and interactivity of mathematics education, hence augmenting student engagement and motivation;

e) interaction with robots engenders memorable learning experiences that enhance long-term information retention;

f) the development of interactive activities allows teachers to allocate more time for the preparation of creative and engaging tasks that foster students' critical thinking and creativity.

   The integration of robotics in the classroom facilitates the enhancement of digital skills and computational thinking, enabling students to acclimatise to contemporary technology and cultivate vital digital competencies for the future. Engaging in games or other forms with educational robots fosters the development of computational thinking skills in students, including problem decomposition, algorithm design, and problem-solving.

The teacher's role in the development and execution of activities with educational robots is critically significant:

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- The teacher's goal is not to convey knowledge or provide solutions; rather, they facilitate specific problem scenarios for the learners to resolve. The children must independently uncover the path to the solution, with the teacher providing suggestions only when necessary;
- The teacher should encourage the children's initiative and creativity;
- Children should be permitted to challenge their views, pursue solutions autonomously, and learn from their errors;
- The teacher must refrain from imposing a specific working method on the children;
- It is advantageous for preschoolers to identify the most appropriate method independently, as not all methods proposed by adults are comprehensible to children. Frequently, a child comprehends another child's explanations more effectively. Logical games are activities conducted mostly in a group or frontal setting, with individual participation occurring infrequently.

A series of pedagogical recommendations for educators on the utilisation of educational robots has been proposed (Zhong & Xia, 2020):

a) educational robots ought to be utilised for brief tasks necessitating adequate operational abilities;
b) the teacher's duty is to inspire pupils, particularly those with lower proficiency levels;
c) less complex robots should be employed to emphasise the mathematical aspects of the robot model.

Tools and resources

The educational robot is a device specifically engineered for use in the learning process. It can manifest in diverse shapes and dimensions, ranging from basic construction kits to intricate, programmable robots. A robot is deemed educational if its principal objective is to foster learning, cultivate practical skills, enhance interactivity in the educational process, and elevate motivation.

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Three primary methodologies facilitate students' acquisition of mathematics using robotics: a) interaction; b) programming; c) design and building (Zhong and Xia, 2020).

To demonstrate that a robot is educational and applicable to mathematics instruction, it must possess the fundamental attributes of an educational robot: a) it is versatile for various activities; b) it enables students to manipulate the robot's movements; c) it can be customised to accommodate the level and specific needs of each student; d) it is constructed from non-toxic materials and features an approachable design.

A comprehensive array of instructional robots includes construction kits, compact programmable robots, robotic arms, and humanoid robots. This list includes small programmable robots that are accessible for usage by both teaching professionals and students. These robots can assume the appearance of diverse insects and animals, designed to be amiable and prepared to support inquisitive children. The most basic aspects of a robot utilised for mathematical tasks include those that can be effortlessly programmed by the learner, comprising a minimum of four directional arrows denoting the robot's movements: forward, backward, left, and right. These arrows may serve as directional indicators and mathematical operators in various educational contexts.
There exist eleven autonomous criteria for the efficacious application of instructional robots in mathematics (Catlin and Blamires, 2010). These principles pertain to three elements: students, teachers, and technology, and they are delineated according to the attributes of these elements.

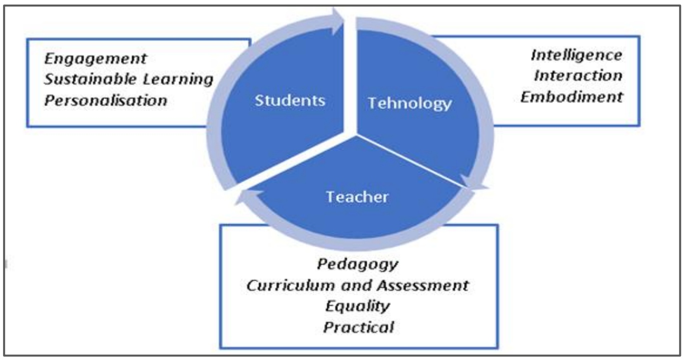

Figure 3.1. The factors in using educational robots (Catlin & Blamires, 2010)

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The examination of these principles results in the formation of a persistent association among the three components. Educational robots employed as instructional tools in the application and development of mathematical concepts facilitate active engagement in these activities. We need to use them judiciously according to the task, with the aim of facilitating the student's acquisition of specific knowledge, stimulating critical thinking, improving their skills or generating new learning scenarios by integrating diverse experiences (Catlin and Blamires, 2010).

The efficient utilisation of educational robots relies on educators and their comprehension of the concept that the robot serves as a beneficial instrument, necessitating proficiency in its proper application. The utilisation of educational robots as a pedagogical resource will elucidate their effectiveness in attaining objectives and the comprehension of aims. The use of educational robots in the instructional process fosters active student participation.

The engagement of pupils with robots involves comprehending the technological functions that the robot is capable of doing. The fundamental operations for instructional robots are movement to the left, right, forward, and backward. Relevant indicators, which young children can easily learn and manipulate over time, supplement these instructions. Mathematical operations are executed according to specific rules, such as the order of operations in an arithmetic expression, which the robot will follow after determining the sequence and will then visualise the trajectory. The analysis of the order of processes, initially abstract, can be visualised and effectively directed in a tangible manner via the robot. Educational robots facilitate good learning experiences in mathematics for kids. Abstract notions that are challenging to visualise and comprehend can be elucidated through the utilisation of robotics to create more defined models. The engagement of robots in mathematics education fosters positive emotional states and facilitates social ties, which enhance attitudes, create conducive learning settings, and improve educational experiences. The engagement of students in mathematics lessons can be augmented by the utilisation of educational robots.

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Engaging the student in the task as a game fosters bonds between the students and the robot: a) the interaction with the physical robot encompasses emotional and social experiences; b) the experience extends beyond young toddlers; c) robots occupy a novel category situated between inanimate objects and human beings (Catlin and Blamires, 2010). We acquire mathematical concepts through intuition and then apply them methodically to real-world situations. As a cohesive mental process associated with reasoning, it relies on memories and subconscious experiences (Catlin and Blamires, 2010). Utilising available resources, robots can generate scenarios that incorporate intuition into the learning process. Educational robots can augment long-term learning by fostering students' metacognitive abilities, life skills, and self-awareness. Children predominantly occupy the educational setting, specifically at school. This educational setting should extend beyond mere information acquisition to encompass socialisation, communication, teamwork, and the cultivation of self-confidence in abilities (Khanlari, 2016; Alqahtani et al., 2022). The utilisation of educational robots facilitates the enhancement of students' cognitive, social, personal, and emotional skills within the learning environment (figure 3.2.).

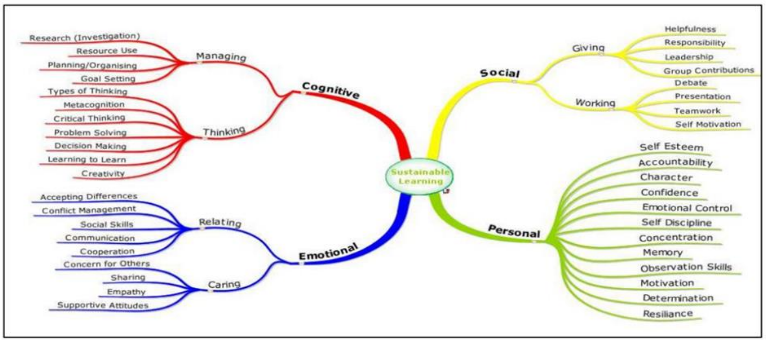

Figure 3.2. Mind map of typical sustainable learning criteria relevant to educational robots. - adapted from the Iowa 4H Program (Catlin & Blamires, 2010)

A nuanced difference exists between instructional robots and pedagogical robotics.

The former is distinguished by the utilisation of specialised robotics kits, frequently costly, that provide a comprehensive examination of hardware and software elements. Conversely, pedagogical robotics seeks to incorporate robotics principles into the conventional

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curriculum, utilising simpler and more accessible technologies, while emphasising the cultivation of computational thinking and problem-solving abilities. Educational robotics provides a rigorous hands-on engagement with technology, whereas pedagogical robotics employs a more holistic methodology, merging insights from several disciplines with fundamental aspects of robotics. This facilitates enhanced accessibility and flexibility in executing operations, without necessitating specialised and costly equipment (Muñoz et al., 2020).

Strategies for active learning and collaboration

Developing a mathematics game necessitates meticulous attention to elements such as: crafting an enjoyable and exploratory experience, presenting suitable challenges, allowing the player a degree of agency, offering assistance when required, and ultimately, incorporating game mechanics that enhance mathematical comprehension (Moon & Ke, 2020).

Arranging an instructional mathematics competition utilising educational robots necessitates the following: a) Developing the instructional game. Analysing the content, organising the resources and supplies, and formulating the scenario; b) The prudent arrangement of it. The configuration of furnishings and the grouping of pupils for effective game execution; c) Acknowledging the instances of the educational game. The cadence and approach to its leadership; d) Promoting active student engagement in the game; e) Fostering a congenial environment; f) The diversity of game components.

To construct the educational game, it is essential to analyse the curriculum content and subject matter, assemble the necessary resources and materials, and formulate the scenario. Successful game execution necessitates the meticulous organisation of pupils, preparation for the activity, and, if required, the arrangement of furniture. To successfully implement the educational game, it is essential to emphasise many pivotal aspects (fig. 3.3) that contribute to attaining the game's objectives.

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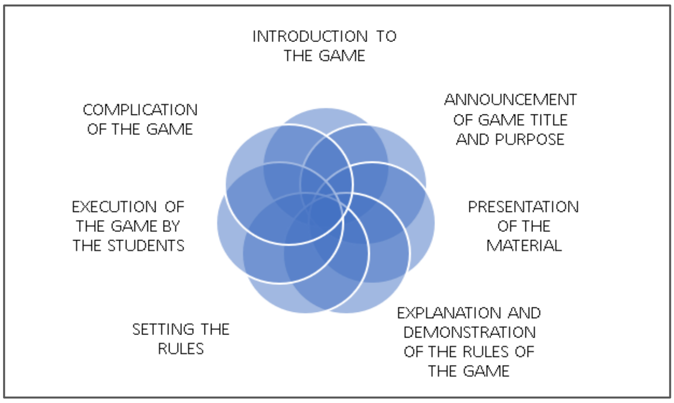

Figure 3.3. Rules of the game (Neacșu, 1988)

The components of a game are: the educational goal, the educational task, the game elements, the game rules, the complication of the game.

The educational objective is described based on the school curriculum, it must be clear and precise. Several characteristics should guide the design of the teaching task: 1) it should focus on a single aspect of the content; 2) it should formulate the problem in such a way that all children can solve it; 3) it should specify what children need to do consciously and concretely during the game to achieve the goal; 4) it should involve intensive training of thinking operations; and 5) it should use knowledge, skills and competences in a variety of ways.

The components of a game are: the educational goal, the educational task, the game elements, the game rules, the complication of the game. The educational objective is described based on the school curriculum, it must be clear and precise.

The didactic task must be developed according to several characteristics:

- it refers to a single aspect of the content;
- the formulation of the problem must be such that it can be solved by all the children;
- specifying what the children need to do consciously and concretely during the game to achieve the proposed goal;
- intensive training of thinking operations;
- utilizing knowledge, skills, and competencies in various ways.

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Models of activities for applying educational robots in math classes:

Example 1. Game of insight. Find the shortest path and continue the calculations. (Fig.3.4).

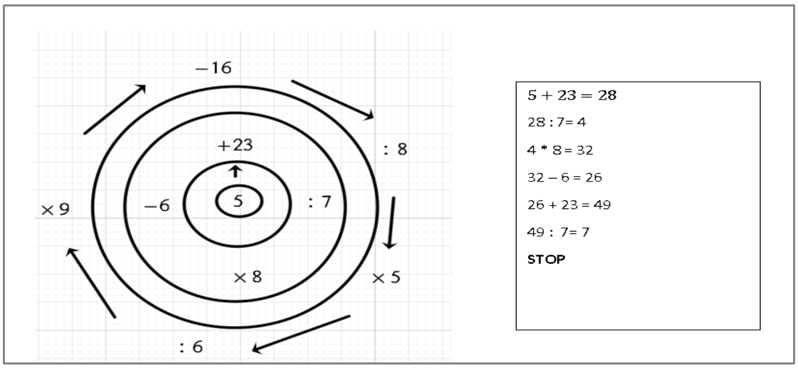

Figure 3.4 Game representation (Neacșu,1988)

Instructions: In the middle, the robot can be placed, guided by the student, and will perform the operations depending on the path chosen.

Example 2. Rational numbers: half, a third, and a quarter of a number (Fig. 3.5.).

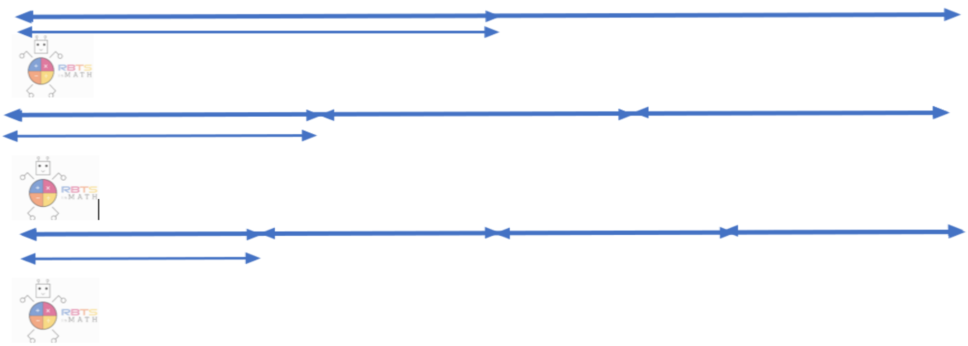

Fig.3.5. Rational numbers

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Instructions: The robot is moved by the student according to the arrow until it reaches the position that indicates half, a third, or a quarter.

Models of scenarios for designing educational games with educational robots:

Model 1.

Title: Four Operation

Learning Outcome: Recognizing the basic concepts of multiplication/division using different strategies that mobilize numerical relationships and properties of operations.
Theory of arithmetic operation properties:

1. Commutativity: A*B=B*A
2. Associativity: A*(B*C)=A*(B*C)
3. Identity element: 1*A=A*1=A
4. Distributivity over addition and subtraction: A*(B+C)=A*B+A*C
5. Multiplication by zero: A*0=0*A=0

Organization steps:

1. Each student creates their own route.
2. Up to 6 students can participate, each having 2 exercises where a property is applied.
3. Each insect represents a property, and each student chooses an insect.

4 Find the exercise associated with the insect and determine the paired insect with another exercise.

5. The Bee Robot always returns to the starting position.

Steps to completion (Fig. 3.6):

1. Choose the Ladybug. The steps are: 1 up, 2 left-3 down, 3 right.
2. Choose the Cricket. The steps are: 3 left - 2 down, 3 right.

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3. Choose the Caterpillar. The steps are: 4 right - 3 down, 5 left.
4. Choose the Butterfly. Steps are: 1 right, 3 down-2 right, 5 up.
5. Choose the Beetle. The steps are: 4 right, 2 up-4 down, 1 left.
6. Choose the Bondar. The steps are: 2 up - 2 right, 3 down.

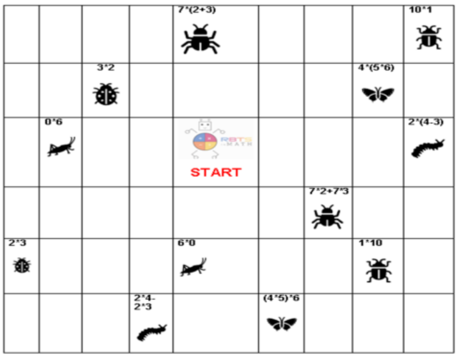

Figure 3.6. Working table for Model 1

<u>*Model 2*. Title: Subunitary and Equiunitary Fractions</u>

<u>Subject:</u> The use of numbers in calculations. The task involves identifying natural numbers within the range of 0 to 10,000, as well as subunitary or equiunitary fractions that have denominators of less than or equal to 10.

Purpose of the activity: Reading and writing subunitary and equivalent fractions Introduction. The game consists of identifying subunit fractions and equivalent fractions, reading and writing them.

<u>Resources include</u>: a) robot or arrows and a toy; b) cards with subunit fractions and equivalent fractions; c) map for the route.

<u>Details in the scenario descriptions</u>. On the map there are cards with unit fractions and subunit fractions. We will select subunit fractions and unit fractions in turn. Each student will choose one of the given types of fractions and create their own route. Upon finding a fraction, they will name the fraction and write down what type of fraction it is.

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Steps to follow:

1. We decide the rules of the game together.

2. Create a mental map of the route to collect the cards.

3. Program the Robot (or put the arrows in the correct order). Press start!

4. We will program the robot to reach each fraction using the corresponding number of steps.

Model 3. Title: The Order of Operations

Subject: Using numbers in calculations. The task involves multiplying numbers within the range of 0 - 1,000,000, ensuring the factors contain no more than three digits, and dividing them into one- or two-digit numbers.

Purpose of the activity: Solving exercises with known operations, respecting the order of operations and the significance of parentheses (only round and square parentheses). Introduction. The game consists of solving exercises with known operations, respecting the order of operations and the significance of parentheses. In an exercise when we have parentheses, the following rules will be observed:First, the operations in the round brackets (small brackets) will be performed. The operations in square brackets are transformed into round brackets, the exercise is transcribed, and then solved further.

Resources:

1. Robot or arrows and a bee toy

2. Cards with numbers on both sides

3. Map for the route

Details in the scenario descriptions

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On the map, there is a card with two sides, one side indicates the order number of the operation, and the other side shows the result for each operation. You need to perform the operation and find the card with the correct result. The obtained result is checked against the found card.
Example exercise: 50+12×[214-240:(16-2×5)]-10×100

Stages of implementation:

1. We decide the rules of the game together.

2. Create a mental map of the path to collect the cards.

3. Program the Bee Bot (or arrange the arrows in the correct order). Press start!

4. The first operation is on the sheet with the result 1 with 10; we program the robot to reach this sheet and the student checks the result in the notebook with the one on the chosen sheet.

5. We proceed with the remaining operations: 2 x 6; 3 x 40; 4 x 174; 5 x 2088; 6 x 1000; 2138 x 1138; and so on, until we reach the end of the exercise.

6. For each result, the student will navigate the path they devised with the robot.

Here are some general tips for teachers during the implementation of educational robot games:

1. Give instructions at the beginning of the game!

2. Each student will individually solve each operation, and the one who completes the operation first will come and find the card with the result using the robot.

3. Encourage the children to speak out loud when they think of the desired result.

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4. Let the children make mistakes. Trying again and discovering the error is part of the game!

5. If you want to increase the speed of task completion, play the game in teams to add competition!

Conclusion

Didactic play, integrated with educational robots, plays a crucial role in the mathematical development of preschool children. By applying Zoltan Dienes' principles, this type of learning not only facilitates the understanding of abstract concepts but also develops essential skills such as critical thinking, collaboration, and creativity. Thus, the integration of play and educational robots in mathematics education not only transforms the learning process but also builds a solid foundation for the development of mathematical skills.

The use of educational robots not only personalizes learning but also provides immediate feedback, helping students quickly correct any gaps. Activities organized within a game framework become memorable, facilitating long-term retention of knowledge. Additionally, the role of the teacher changes from being an information provider to a facilitator of learning, encouraging students to discover solutions and develop their creativity. This approach not only improves student engagement but also develops their digital skills and computational thinking, thus preparing them for the future. Therefore, the collaboration between teachers and educational robots in the educational process is essential for creating a dynamic and efficient learning environment where each student has the opportunity to progress at their own pace and develop the necessary skills to cope. They not only facilitate learning through interactivity and adaptability but also contribute to the development of practical skills and critical thinking. The essential characteristics of educational robots, such as movement control and the ability to be customized for different learning levels, make them accessible and attractive to students. By using these robots, teachers can transform abstract concepts into concrete experiences, thereby improving the understanding of mathematics and promoting active student engagement. Moreover, the approach through carefully organized educational games can stimulate cooperation and communication among students, creating a pleasant

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and motivating learning environment. Thus, the integration of educational robots into mathematical activities not only enhances the learning process but also contributes to the development of essential skills for the future, preparing students for a constantly changing world. It is crucial for teachers to understand how to use these resources effectively to maximize the educational benefits that robots can bring.

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Chapter 4: Designing Engaging Classroom Activities in Flipped Learning (SCUOLA DI ROBOTICA, Filippo Bogliolo, MA)

Explanation and principles

Flipped learning represents a fundamental shift in the way education is structured. By reversing the traditional model of instruction, it positions students as active participants in their own learning journey. In robotics education, this approach is particularly impactful, as it fosters curiosity, autonomy, and hands-on problem-solving—all of which are critical in understanding the interdisciplinary nature of robotics.

Seymour Papert, the father of constructionism, argued that *"learning happens most effectively when people are actively involved in designing and creating things that are meaningful to them."* Flipped learning embraces this ethos by moving direct instruction—lectures, readings, or video lessons—to pre-class sessions, while dedicating classroom time to exploratory and collaborative activities. This shift aligns perfectly with robotics education, where abstract principles in mathematics, programming, and engineering come to life through tangible projects.

Core Principles of Flipped Learning in Robotics

1. **Student-Centered Learning:**
   Students engage with foundational content (e.g., tutorials on robotics concepts) independently before class. This encourages self-directed exploration and ensures they arrive prepared for hands-on tasks.
2. **Active Learning in Class:**
   Class time is devoted to applying knowledge through collaborative projects. For instance, students might work in teams to design and program a robot capable of navigating a maze, solving real-world problems, or simulating natural systems.
3. **Integration of Digital Tools:**
   Robotics education benefits from digital platforms like Scratch and mBlock, which allow students to experiment with coding and logic at home. Tools like these empower learners to visualize abstract mathematical and programming concepts in a playful, intuitive manner.

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4. **Constructivist Pedagogy:**
   Rooted in Papert's ideas, flipped learning emphasizes "learning by doing." Students build robots, program them, and observe the outcomes of their work, engaging both cognitively and physically with the material.
5. **Personalization and Accessibility:**
   Flipped learning allows for differentiated instruction. Students can learn at their own pace outside the classroom, revisiting challenging topics as needed, while teachers provide targeted support during in-class activities.

Theoretical Foundations

Flipped learning is deeply influenced by thinkers like Seymour Papert and Mitchel Resnick. Resnick, a key figure at the MIT Media Lab, emphasized the importance of creating environments where learners can "imagine, create, and reflect." This idea is central to flipped robotics education, where students move from consuming information to producing solutions.

Similarly, Shannon's theories on information flow and systems inspire robotics education by highlighting the importance of feedback and iteration. Flipped learning leverages this by incorporating iterative design cycles: students analyze problems, test solutions with their robots, and refine their approaches.

Why Robotics Education Benefits

Robotics education is uniquely suited to flipped learning because of its interdisciplinary nature. Concepts in physics, engineering, and mathematics are inherently more engaging when applied in dynamic, real-world contexts. For example:

- **Mathematics:** Students can explore geometry and algebra by programming robots to trace shapes or calculate optimal paths.
- **Engineering:** Building and troubleshooting robots deepens understanding of mechanical and electrical systems.
- **Problem-Solving:** Students apply logic and critical thinking as they debug programs and refine robot behaviors.

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By embracing flipped learning, educators empower students to become co-creators of their education. This model not only enhances engagement but also instills critical 21st-century skills such as collaboration, resilience, and creativity. These principles, when applied to robotics education, ensure that learning is both meaningful and memorable.

Benefits for teachers

Flipped learning in robotics education offers several advantages for teachers:

Enhanced Engagement: Teachers can focus on guiding students through complex, hands-on tasks instead of delivering repetitive lectures.

Individualized Support: Class time is spent addressing specific challenges and encouraging collaboration, creating opportunities for personalized instruction.

Better Learning Outcomes: By allowing students to explore concepts before class, they arrive prepared and motivated, leading to deeper understanding and retention.

Innovation in Teaching: Drawing on principles from Shannon's theories of information and interactivity, teachers can incorporate dynamic, feedback-rich systems to make learning more impactful.

These benefits help educators foster an environment where students become active participants in their own learning journey.

This section outlines the advantages teachers can gain by applying flipped learning in robotics education.

Here's a detailed look at how flipped learning benefits teachers in robotics-focused classrooms:

1. Enhanced Student Engagement

Flipped learning allows teachers to use class time for hands-on robotics activities, which naturally engage students. Rather than lecturing on abstract concepts like algorithms or sensor integration, teachers can supervise as students experiment, build, and program their robots. This active involvement not only motivates students but also reduces classroom management challenges, as students are more focused and enthusiastic.

2. More Time for Individualized Instruction

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Pre-class preparation ensures that students arrive with a baseline understanding of the topic. This frees up class time for teachers to:

Provide targeted support to students who struggle with specific concepts.

Challenge advanced learners with extension tasks, such as optimizing robot designs or programming efficiency.

Facilitate small group discussions or peer mentoring to deepen comprehension.

This adaptability allows teachers to address the diverse needs of their students more effectively.

3. Opportunities for Creativity and Innovation

Flipped learning gives teachers the flexibility to design creative and interactive lesson plans. Robotics education naturally lends itself to project-based learning, where teachers can:

Integrate storytelling, such as programming robots to act out a narrative or solve a fictional problem inspired by Seymour Papert's constructionist ideas.

Incorporate real-world challenges, like programming robots for environmental clean-up simulations.

Use tools like Scratch or LEGO robotics kits to create immersive, gamified experiences.

This creative approach keeps both teachers and students engaged and excited about learning.

4. Efficient Use of Class Time

By offloading direct instruction to pre-class video lessons and animated PowerPoints, teachers can dedicate more in-class time to:

Observing and assessing student collaboration and problem-solving skills.

Facilitating discussions on robotics concepts, such as the principles of sensors and programming logic, inspired by Shannon's theories of information flow.

Encouraging iterative design processes, where students refine their robot programs based on trial and error.

This efficiency ensures that every minute of class time is productive and impactful.

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5. Improved Learning Outcomes

Teachers using flipped learning often report better academic performance and student confidence. When students engage with video lessons and resources at their own pace, they are better prepared for in-class activities. This approach helps:

Build foundational knowledge before diving into complex robotics tasks.
Reinforce difficult concepts through repetitive exposure to pre-class materials.
Foster collaborative skills during group robotics projects, aligning with the constructivist principles of Papert and Resnick.

6. Professional Growth

Implementing flipped learning encourages teachers to explore innovative instructional methods and technology tools, enhancing their professional development. By integrating robotics and flipped learning, teachers gain:

Familiarity with cutting-edge educational technologies, such as robotics platforms (e.g., LEGO Spike Prime, mBot) and digital content creation tools.
Opportunities to collaborate with peers and organizations like Scuola di Robotica, sharing best practices and gaining mentorship from leaders like Emanuele Micheli.
A deeper understanding of how to balance digital and in-person teaching methods, a critical skill in modern education.

7. Building a Collaborative Classroom Culture

Flipped learning naturally fosters a more collaborative classroom environment. Teachers can design activities where students work in pairs or small groups to solve problems, build robots, and debug code. This collaborative approach:

Encourages students to learn from each other, reducing reliance on the teacher for answers.

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Creates a supportive community where students feel empowered to explore and make mistakes.

Allows teachers to observe how students interact and identify potential leadership qualities or areas for improvement.

8. Flexibility in Teaching Methods

Flipped learning offers teachers the flexibility to tailor lessons to their specific classroom needs. For example:

For beginners: Focus on foundational robotics concepts through simple pre-class materials and guided in-class activities.

For advanced learners: Incorporate challenging tasks, such as integrating AI or IoT (Internet of Things) into robotics projects.

For diverse classrooms: Use differentiated materials, like videos in multiple languages or adjustable-paced lessons, to ensure accessibility for all students.

9. Empowerment Through Technology

Flipped learning aligns with modern educational trends by emphasizing digital tools. Teachers benefit from access to:

High-quality pre-made resources, such as videos from MIT Media Lab.

Tools for tracking student progress, like formative quizzes embedded in video lessons.

Technology that simplifies lesson preparation, allowing teachers to focus on meaningful interaction during class.

10. Long-Term Impact on Teaching Practices

Adopting flipped learning in robotics education has a lasting impact on teaching practices. It encourages teachers to:

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Embrace a student-centered approach, which aligns with Papert's belief in empowering learners.
Experiment with innovative pedagogies that can be applied across subjects.
Build confidence in integrating technology into the curriculum, preparing them for future educational advancements.

Tools and resources

Implementing flipped learning in robotics-focused classrooms requires the right tools and resources:

Digital Platforms: Tools like Scratch, mBlock, and Arduino IDE offer accessible ways for students to explore robotics programming before class.
Video Lessons: Inspired by resources from the MIT Media Lab, high-quality video tutorials provide foundational knowledge for students to engage with at their own pace.
Collaborative Robotics Kits: Kits like LEGO Education Spike Prime encourage hands-on collaboration during in-class sessions.
Assessment Tools: Applications to monitor student progress, such as formative quizzes and real-time feedback systems, ensure learning objectives are met.
Teacher Support Networks: Collaborating with organizations like Scuola di Robotica provides educators with workshops, lesson plans, and mentorship to refine their flipped learning strategies.

Strategies for active learning and collaboration

To maximize the potential of flipped learning in robotics education, teachers can implement these strategies:

Guided Exploration: Begin each in-class session with a challenge based on pre-class material. For instance, students can design and program a robot to solve a specific problem.

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Peer-to-Peer Learning: Assign collaborative projects where students work in pairs or small groups, exchanging ideas and refining each other’s approaches.
Hands-On Problem Solving: Create real-world scenarios for robotics challenges, inspired by Shannon’s theories on problem-solving and Papert’s constructionist approach.
Reflection and Feedback: Use tools like journals or quick reflection sessions to help students connect their activities to broader robotics principles.
Gamification: Introduce elements of competition or rewards to motivate students, such as races or obstacle course challenges for their robots.
These methods encourage students to take ownership of their learning, aligning with Mitchel Resnick’s belief in “designing, creating, and inventing as central to learning.”

Conclusion

Flipped learning in robotics education is not just a teaching model; it’s a philosophy that transforms classrooms into hubs of innovation and collaboration. By leveraging tools, fostering active learning, and embracing the principles of educators like Seymour Papert and Mitchel Resnick, teachers can empower their students to become confident, capable learners. As organizations like Scuola di Robotica and thought leaders like Emanuele Micheli have shown, the integration of flipped learning in robotics can bridge the gap between theory and practice, preparing students for a future where creativity and problem-solving are paramount.

Educators are encouraged to adopt these strategies and adapt them to their unique classroom contexts, ensuring every student experiences the joy of learning through robotics.

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Chapter 5: Integrating Robotics to Teach Mathematics' skills, knowledge (University of Latvia, Ineta Helmane, PhD)

Essence and principles

The integration of robotics into mathematics education is becoming increasingly recognized as a potentially transformative approach to learning, offering students hands-on, practical experiences that bridge the gap between abstract mathematical concepts and their real-world applications. The integration of robotics into mathematics education has been demonstrated to enhance students' engagement with STEM concepts, facilitating problem-solving and critical thinking skills. The utilization of robotics tasks, such as programming robots to follow specific paths or calculate angles, provides a tangible representation of mathematical principles, thereby fostering greater engagement and a deeper understanding of abstract concepts (Varaman et al., 2024; Chen et al., 2023).

The very nature of robotics serves to bridge the gap between theory and practice. In mathematics, where abstract concepts such as geometry, algebra, and calculus may appear remote from students' everyday experiences, robotics offers a means of making these concepts tangible and accessible. When students work with robots, they engage in activities that naturally demand mathematical reasoning, including the calculation of distances and angles, as well as the understanding of ratios, measurement, and the application of programming algorithms (Kim et al., 2021). This process can serve to demystify mathematics, transforming it from a series of calculations on paper to a powerful tool for problem-solving and innovation. The integration of robotics into the learning process facilitates the internalization of fundamental mathematical principles through the embedding of these principles in interactive tasks that offer immediate feedback. To illustrate, the calculation of a robot's trajectory to follow a precise path requires the application of geometry, while the programming of the robot's movement necessitates the integration of algebraic reasoning (Lopez-Caudana, 2020).

Core Principles for Integrating Robotics in Teaching Mathematics

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In order to achieve successful integration of robotics in mathematics instruction, educators must adhere to a set of core principles that optimize learning outcomes and foster students' engagement and understanding:

- Hands-On Learning and Experiential Engagement

Hands-on learning is a fundamental aspect of robotics education, as it necessitates student engagement with the tangible world. The manipulation and measurement of real objects in robotics projects affords students a multisensory experience that serves to reinforce their comprehension of mathematical concepts. Experiential learning enables students to test hypotheses, observe outcomes and modify their approach based on the results, thereby mirroring the scientific method and fostering mathematical thinking (Varaman et al., 2024; Suarez, et al., 2023).

- Problem-Solving and Critical Thinking

The field of robotics is inherently problem-based, necessitating that students address genuine, real-world challenges through a process of trial and error. The process of problem-solving fosters the development of critical thinking skills in students by encouraging them to approach tasks in a methodical manner, evaluate a range of potential solutions, and apply logical reasoning to adapt their approach when necessary. The ability to work through challenges in a resilient and adaptable manner is an essential skill for mathematical reasoning and comprehension (Fan & Xu, 2024).

- Interdisciplinary Connections

Robotics offers an interdisciplinary platform that integrates mathematical, scientific, technological, and engineering principles. When students engage in robotics activities, they simultaneously apply mathematical concepts alongside principles of physics (e.g. force and motion) and engineering (e.g. building structures and mechanisms). This integrated approach reflects the way in which mathematics is applied in the real world, enabling students to grasp its significance and usefulness beyond the classroom (Hsu &Tsai, 2022).

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- Visualizing Mathematical Concepts

The capacity to visualize is a pivotal element of mathematical education, particularly in the context of abstract concepts. The use of robotics enables students to gain a practical understanding of mathematical principles, such as measuring and calculating angles or understanding velocity. The utilization of robotics as a visualization tool enables educators to deconstruct intricate mathematical concepts, thereby facilitating the development of mental models and enhancing students' conceptual comprehension (Varaman et al., 2024).

- Encouraging Collaboration and Communication

Robotics projects frequently entail collaborative endeavors, which facilitate the exchange of communication, teamwork, and the sharing of ideas. The collaborative environment allows students to engage in discourse on mathematical concepts, learn from one another, and elucidate their reasoning processes. The articulation of mathematical ideas is of paramount importance for the consolidation of knowledge and the refinement of understanding. It is essential that students are able to convert abstract thought into communicable terms (Demetroulis et al., 2023).

- Feedback and Iterative Learning

One of the most significant advantages of robotics in the field of education is the immediate feedback that students receive from the actions of their robots. Should a robot's movement deviate from the intended result, students are able to rapidly identify and rectify any errors. This iterative learning process serves to reinforce mathematical concepts, as students are required to calculate, test and adjust parameters in order to achieve the desired outcome, thereby refining their understanding through continuous improvement (Vando et al., 2022).

Practical Applications of Robotics in Mathematics Education

The integration of robotics principles into the educational curriculum enables educators to develop activities that effectively reinforce mathematical concepts. By aligning robotics projects with the stated curriculum goals, teachers can enhance student engagement and understanding of mathematical concepts through the use of hands-on, practical applications.

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This approach encourages active learning and facilitates students' comprehension of the practical applications of mathematics. When these principles are applied in the context of educational robotics, educators are able to design activities that align with the mathematical curriculum:

- Geometry and Measurement: The process of programming a robot to navigate a maze can facilitate the acquisition of knowledge and understanding of fundamental concepts related to angles, distances, and spatial reasoning. By calculating the requisite turns and movements, students hone their ability to measure and apply geometric principles (Magallán-Ramirez, 2021).
- Algebra and Ratios: The utilization of speed and distance calculations enables students to investigate ratios and algebraic reasoning. By way of illustration, the determination of the appropriate speed for a robot to reach a target within a specified timeframe serves to reinforce comprehension of proportion and algebraic relationships.
- Probability and Statistics: The utilization of sensors on robots enables students to gather data on a range of surfaces and environments. This data can then be subjected to statistical analysis, allowing for the interpretation of results and an understanding of probability.
- Programming and Algorithmic Thinking: The fundamental principles of programming robot paths and sequences provide an introduction to algorithms, which are a mathematical methodology for problem-solving that employs a logical, step-by-step process. This provides a foundation for an understanding of the functions of algorithms in both mathematics and computer science.

The integration of robotics into mathematics education offers a multitude of advantages, yet it also presents a number of considerable challenges that educators must address. The following paragraphs present a selection of key points from recent articles that reflect on these issues:

- The integration of robotics into mathematics education presents a number of challenges, despite the substantial benefits it offers. It is possible that teachers may require further training, additional resources and further support in order to implement robotics effectively in the classroom. It is also imperative to guarantee access to robotics equipment and technology across a diverse range of educational institutions and student demographics in order to promote equity in STEM education.
- In the future, research into the impact of robotics on mathematics education is set to become a significant area of study. The potential for advances in artificial intelligence

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and machine learning to facilitate new opportunities for personalized learning experiences may serve to further enhance the role of robotics as a tool for mathematics instruction. As technology advances, the incorporation of robotics in educational settings is poised to become more prevalent, offering student's increasingly diverse avenues to engage with the intricacies and practical applications of mathematics.

Benefits for teachers who Integrate Robotics to Teach Mathematics' skills, knowledge.

The integration of robotics into mathematics education is effecting a transformation in the classroom environment, engaging students in hands-on, interactive learning experiences. For educators, this approach has the dual benefit of enhancing the learning outcomes for their students while also affording them a number of professional advantages. The integration of robotics into mathematics education, when combined with the flipped learning model, whereby students are introduced to content at home and then engage in active learning activities in class, has the potential to enhance the effectiveness and impact of the learning experience. Here, we outline the key advantages teachers gain by incorporating robotics and flipped learning in the mathematics curriculum:

1.Enhanced Student Engagement and Motivation

One of the most immediate benefits for educators who integrate robotics into mathematics lessons is the enhanced student engagement and motivation. The incorporation of robotics into mathematics curricula introduces a practical and tangible dimension to mathematical concepts, enabling students to perceive the real-world applications of their skills. In a flipped learning environment, students arrive at class prepared to engage in hands-on activities rather than passively listening to instruction. This active learning environment has the additional benefit of making mathematics more engaging for students, while also reducing the challenges associated with classroom management, as students are highly engaged in collaborative projects (Varaman et al., 2024).

2.Improved Student Understanding of Mathematical Concepts

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Robotics provides a conduit between abstract mathematical concepts and their real-world applications, facilitating a more intuitive comprehension of complex ideas among students. When students apply mathematical concepts to the construction and programming of robots, they are able to observe the theories in action, thereby making the learning process both meaningful and memorable. By employing the flipped learning approach, educators can utilize class time to enhance students' comprehension, guiding them through hands-on problem-solving activities that reinforce the concepts they have studied at home. This approach facilitates a more personalized and experiential learning model, wherein students can promptly apply mathematical theories, thereby enhancing comprehension and retention (Hsu et al., 2022).

3.Increased Classroom Efficiency

The implementation of flipped learning in a robotics-focused classroom setting liberates valuable in-class time for educators, enabling them to direct their attention towards student-centric activities. Upon completion of preliminary lessons at home, students arrive at school prepared to engage in robotics projects, thereby enabling teachers to function more as facilitators than as traditional instructors. This transition reduces the amount of time spent on lecture-based instruction and optimizes time for one-to-one guidance, group work and skill development. Teachers are thus better positioned to assess each student's progress, provide timely support, and adjust lessons according to individual needs (Learning Futures, 2019).

4. Development of 21st-Century Skills

The integration of robotics in the classroom fosters the development of essential 21st-century skills, including problem-solving, critical thinking, and collaboration, among students. For educators, fostering these skills in students aligns their pedagogical approach with contemporary educational objectives and better prepares their students for future careers. The undertaking of robotics activities frequently necessitates the formation of teams amongst students, enabling them to collectively address intricate projects. This provides an organic setting for the cultivation of collaborative abilities. The flipped classroom model also lends support to this approach, as students arrive prepared to engage with the material and collaborate in real time, thereby practicing and applying these soft skills in a dynamic and supportive setting (Negrini, 2023).

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5. Professional Growth and Increased Teaching Satisfaction

Teachers who integrate robotics into their mathematics curriculum frequently discover new competencies and engage with innovative teaching practices, thereby facilitating their own professional growth. Such teachers become adept at managing technology-rich environments, adapting lessons to flipped learning models and maintaining currency with educational trends in STEM (Science, Technology, Engineering and Mathematics). The integration of robotics and flipped learning has been shown to benefit students, as well as contribute to greater job satisfaction for teachers, who observe positive impacts on their students' learning journeys (Aurini et al.,2017; Papadakis, 2019).

6. Access to Enhanced Data for Student Assessment

The flipped learning approach enables educators to utilize a range of digital tools and platforms to monitor student engagement and comprehension prior to the lesson. This allows for a more comprehensive understanding of each student's understanding of mathematical concepts. The utilization of robotics projects affords educators the opportunity to gain further insights into their students' abilities. This is achieved through the observation of students' problem-solving processes, collaborative skills and adaptability in real-time. Collectively, these assessment opportunities afford teachers a comprehensive perspective on student advancement, empowering them to offer tailored feedback and adapt their instruction to better align with the diverse learning requirements of their students (Seng, 2023).

7. Increased Creativity and Flexibility in Lesson Planning

The integration of robotics and flipped learning in mathematics enables a more flexible and creative approach to lesson planning. Teachers are no longer constrained by the limitations of traditional lesson structures and are thus able to construct modular, interactive lessons that are responsive to the diverse learning styles of their students. The nature of robotics projects lends itself to open-ended exploration. With flipped learning, teachers are able to establish a foundation for these projects remotely, using class time for more in-depth investigation. This flexibility enables educators to experiment with a range of pedagogical approaches, which may result in more engaging and effective learning experiences (Fung et al., 2021).

8. Strengthened Student-Teacher Relationships

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The involvement of teachers in robotics projects allows them to assume a mentorship role, rather than that of a mere lecturer. In this capacity, educators can facilitate students' navigation of challenges, acknowledge their achievements, and cultivate resilience, thereby forging more robust and nurturing connections. Flipped learning facilitates the development of these interpersonal connections by liberating in-class time for individual interactions. This allows educators to shift their focus from the delivery of lectures to the provision of guidance and assistance, which is particularly beneficial for fostering a supportive learning environment. The fostering of positive relationships within the classroom environment is conducive to a learning environment where students feel comfortable taking risks and exploring new ideas, both of which are crucial for effective learning in mathematics.

9. Staying Ahead in a Rapidly Evolving Education Landscape

The integration of robotics in mathematics education is becoming increasingly prevalent, and educators who adopt this technology are well-positioned to remain at the vanguard of educational innovation. The integration of robotics and flipped learning in the classroom demonstrates the adaptability, creativity and commitment of teachers to providing their students with relevant, future-focused skills. Such a forward-thinking approach not only serves to enhance the curriculum vitae of the teacher in question, but also prepares them for further advancements in STEM education. This, in turn, makes them more competitive in an increasingly tech-focused educational landscape.

Tools and resources

The integration of robotics into mathematics teaching has the potential to transform student engagement and comprehension. The combination of hands-on robotics activities with the flipped learning model – whereby students engage with foundational content at home and apply their learning in practical contexts during class time – enables educators to create dynamic learning environments that reinforce mathematical skills in innovative ways. To ensure the effectiveness of this approach, teachers require access to the appropriate tools and resources for its successful implementation. This article presents a selection of essential tools, platforms and resources that support the integration of robotics and mathematics in a flipped learning classroom.

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Robotics Kits and Platforms

The core of any mathematics curriculum with a focus on robotics is the utilization of kits and platforms that facilitate the construction and programming of robots by students. The following options represent excellent resources for integrating robotics with mathematics:

- **LEGO Education SPIKE Prime**: SPIKE Prime has been designed for students aged 10 and above. It combines LEGO building with programmable robotics, making it an ideal tool for visualizing mathematical concepts such as geometry, ratios and measurement. The SPIKE Prime software features a user-friendly interface that enables educators to construct lessons that align with mathematical standards.

https://spike.legoeducation.com/

LEGO Education SPIKE Prime is an effective tool for making mathematical concepts engaging and interactive, particularly for students in middle school. The following examples illustrate the ways in which SPIKE Prime can be used in mathematics lessons (see Table 1):

Table 1 Activities with LEGO Education SPIKE for Mathematics

Title of Activity	Activity	Math Skills	How It Works
Understanding Coordinates and Graphing	Students can create a robot that moves on a grid to help them understand coordinate systems and graphing. For example, program	Coordinates, positive and negative integers, plotting points on a grid.	Program the robot to move forward, backward, left, or right, using given steps (representing units). Students can practice plotting the

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	the robot to start at a given point (like the origin, 0,0) and navigate to other points on a coordinate plane.		path on a graph as they code the robot to reach specific coordinates.
Exploring Geometry with Shape Drawing	Have students program the SPIKE Prime robot to draw shapes such as squares, rectangles, triangles, or even complex polygons.	Understanding angles, polygons, perimeter, and area.	Students calculate the turning angles and side lengths needed for different shapes. By measuring, planning, and programming, they reinforce concepts like angle degrees, side lengths, and geometric properties.
Using Ratios and Proportions for Scaling	Design a scaled model with SPIKE Prime, then program it to move specific distances that represent real-world scaled distances.	Ratios, proportions, scaling.	For example, students can create a model that moves 10 cm to represent 1 km. They calculate proportions to scale down distances for the model to simulate real-world movement or sizes,

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			applying their understanding of ratios in a concrete way.
Calculating Speed and Distance in Motion	Create a racecourse and program the SPIKE Prime robot to move from start to finish, timing the run. Students can measure the distance covered and calculate speed.	Distance, time, speed, and rate calculations.	Use sensors to measure distance or manually measure the course, then time the robot's movement. Students can use the formula to calculate speed, and compare the effects of different programming parameters on the speed.

- **VEX Robotics Kits**: VEX Robotics offers a range of kits that are appropriate for use by individuals of varying age groups. The VEX GO kit is designed for younger students, while the VEX IQ system is intended for middle and high school students. Both kits allow students to program robots to solve mathematical challenges, including tasks requiring coordinate geometry and sensor-based distance measurements.

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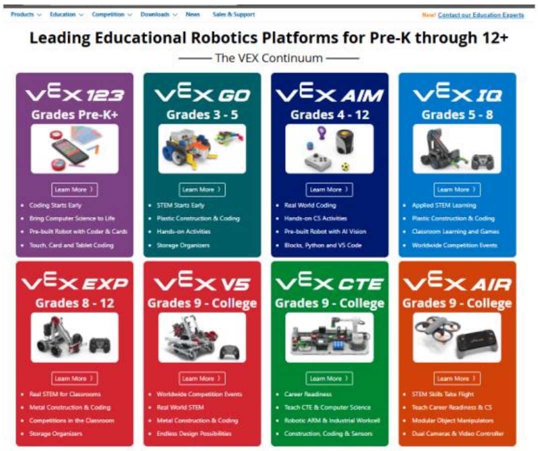

https://www.vexrobotics.com/

VEX Robotics Kits can be effectively used in mathematics education through a variety of engaging activities and projects. Here are some examples of how they can be integrated into math lessons:

- Robo Rally and Robot Math: One of the activities, called "Robo Rally," involves students using robots to navigate a course they design. This activity encourages the application of mathematical concepts such as distance, scale, and geometry. Students must calculate the shortest paths, use proportional reasoning to scale their designs, and understand spatial relationships, all while programming their robots to perform specific tasks;
- Real-World Applications: Teachers can design lessons that require students to use measurements and geometry in constructing their robots and programming their movements. For example, students might need to determine the appropriate angles for robot joints to achieve desired movements or calculate the speeds at which their robots must operate to complete a task in a set time frame;
- STEM Labs and Challenges: VEX Education provides STEM Labs that integrate math skills into hands-on robotics challenges. These labs encourage students to use math in problem-solving scenarios, such as programming robots to solve mazes, where they must apply concepts like measurement, angle calculation, and coordinate systems;
- Coding and Mathematical Concepts: In activities where students code their VEX robots, they learn about sequences and algorithms, which inherently involve mathematical thinking. They may use loops, conditionals, and variables, all of which require understanding of mathematical principles;
- Cross-Disciplinary Integration: VEX robotics projects often cross over into science and engineering, allowing students to see the practical applications of math in various fields. For instance, while programming robots for a science experiment, students can

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apply statistical analysis to interpret their data, thus combining math with scientific inquiry https://www.vexrobotics.com/

VEX Robotics Kits can be very effective in teaching various math concepts through hands-on, applied learning. Here are some examples of how to use VEX Robotics in math education (see Table 2). VEX Robotics kits make abstract math principles accessible through problem-solving and experimentation, making math both practical and engaging for students.

Table 2 Activities with VEX Robotics Kits for Mathematics

Title of Activity	Activity	Math Skills	How It Works
Measurement and Unit Conversion	Build a robot that can travel set distances and measure its speed. Students then use measurements to calculate distance, time, and speed.	Measurement, unit conversion, distance calculations, and the relationship between speed, distance, and time.	Program the robot to move a specific distance, measure its time to travel, and calculate the speed. Students can use various units (e.g., cm/s or m/s) and practice converting between them.
Graphing and Coordinate Plane	Program the VEX robot to navigate on a coordinate grid, where students assign coordinates and observe the robot's path.	Coordinate graphing, positive and negative values, and spatial awareness.	Students can set the robot to start at the origin and navigate to specific points on a coordinate plane, helping them understand graphing and the relationship between coordinates and movement.

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Geometry and Angles	Design a robot to draw shapes, such as triangles or polygons, by programming specific angle turns.	Angles, properties of polygons, perimeter, and area.	Students program the robot to turn at calculated angles for each shape. For example, for a square, the robot needs to turn 90 degrees four times. This activity helps students visualize and calculate angles, reinforcing geometry concepts
Data Collection and Statistics	Use sensors on the VEX robot (e.g., distance sensors) to collect data and analyze it.	Data collection, mean, median, mode, and data interpretation.	Program the robot to measure various distances or collect temperature data in different locations. Students can then analyze this data to calculate average values or identify patterns, learning fundamental concepts in statistics.
Ratios and Proportions	Set up challenges where students must calculate the correct ratio for gears to	Ratios, proportions, and understanding mechanical advantage.	By adjusting gear ratios, students can observe how the robot's speed or

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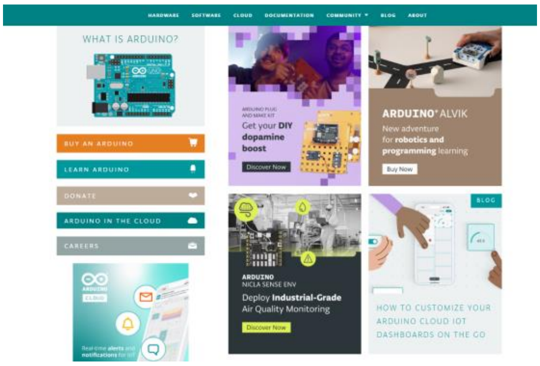
	make the robot achieve a specific task, like moving faster or carrying more weight.		power changes. They calculate the ideal gear ratio to achieve a target speed or torque, reinforcing the concept of ratios and proportions.

- **Arduino**: Arduino kits, despite their more sophisticated nature, are adaptable instruments that enable educators to address mathematical concepts such as algebra, trigonometry, and linear equations. Arduino kits facilitate sophisticated programming and are particularly suited to high school students who are prepared to engage with demanding mathematical applications.



https://www.arduino.cc/

Using Arduino in mathematics education is an innovative way to connect abstract math concepts with practical, hands-on applications. Here are some examples of how Arduino can be used to enhance math learning:

- Real-World Measurements and Data Analysis: Arduino kits can be equipped with sensors to measure environmental variables like temperature, light, or distance. Students can collect and analyze real-time data, applying statistical concepts like mean, median, and mode to their datasets. This type of project also involves graphing, which reinforces skills in data visualization and interpretation;
- Geometry and Trigonometry through Motion and Angles: With Arduino, students can build projects such as robotic arms or vehicles that require precise movement control. By programming the Arduino to move a specific distance or at particular angles, students explore concepts of angles, distance calculations, and trigonometric

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functions. This brings geometry to life, showing how it can be applied in fields like robotics and engineering;

- Mathematics of Coding: Programming Arduino involves logic and sequencing, which overlap with math skills. Tasks like calculating the timing of LED lights, controlling motor speeds, or adjusting sensor thresholds introduce algebraic thinking. Projects requiring loops, conditionals, and iterative calculations foster logical reasoning, a foundational skill in both math and programming;
- Calculus and Rate of Change: More advanced math students can use Arduino to examine calculus concepts. For example, by measuring a sensor's response to changing light conditions, students can explore rates of change, slopes, and derivatives. Projects like simulating physics-based experiments, such as falling objects with distance sensors, can deepen understanding of calculus applications;
- Interdisciplinary Projects with Real-World Applications: Arduino-based projects like building an automatic light sensor or a temperature control system integrate math with science and engineering. Students might calculate voltage changes, power usage, or other metrics requiring basic arithmetic and conversion calculations, which can make learning more engaging and show the practical value of math skills;
- Integrating Arduino into math lessons supports hands-on learning, creativity, and analytical skills, as well as bridging math with real-world applications. This approach is known to increase engagement and provide students with a deeper, more intuitive grasp of mathematical principles. Teachers have found it to be effective in STEM-focused classrooms where interdisciplinary learning is encouraged https://www.arduino.cc/

Here are four activity ideas using Arduino to teach various mathematics concepts (see Table 3). Each of these activities makes abstract math concepts tangible, encouraging students to apply math skills in a real-world, hands-on way. By combining Arduino with mathematics, students gain practical experience that deepens their understanding of data analysis, geometry, algebra, and number systems.

Table 3 Activities with Arduino for Mathematics

Title of Activity	Activity	Math Skills	How It Works
Data Collection and Statistics with Temperature Sensors	Equip an Arduino board with a temperature sensor, and program it to take temperature	Data collection, calculating mean, median, mode, and interpreting trends.	Students can compile the readings into a dataset and use their math skills to find the average

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	readings at regular intervals throughout the day. Students can then collect this data over time and use it to calculate statistical measures.		temperature for the day, identify the most frequent temperature (mode), and discuss any trends or patterns observed over time.
Exploring Geometry with Servo Motor Angles	Using an Arduino board and a servo motor, challenge students to make the servo rotate to specific angles that correspond to different geometric shapes (e.g., triangles, squares). They could also program the servo to rotate continuously at 45°, 90°, and 120° to visualize these angles.	Understanding angles, measuring degrees, properties of polygons.	Students can calculate the angles necessary for each turn of the servo motor to mimic specific shapes. For example, moving the servo to 90° repeatedly simulates the angles in a square, and they can measure how the servo's programmed angles correspond to each shape.
Using LED Lights to Demonstrate Binary Math and Powers of Two	Connect multiple LED lights to an Arduino and program them to turn on and off in binary sequences.	Binary numbers, powers of two, sequences, and place values.	Each LED represents a place in the binary system (1, 2, 4, 8, etc.). Students can count in binary by turning the LEDs on

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	For example, students can make LEDs light up in sequences corresponding to binary numbers from 0 to 15.		and off in the right sequence. This activity illustrates how binary works in digital systems and reinforces understanding of exponential growth in powers of two.
Graphing and Rate of Change with Distance Sensors	Set up an Arduino with an ultrasonic distance sensor to measure the distance between the sensor and an object over time. Students can move an object closer or further and record the changing distances, plotting them on a graph to visualize the rate of change.	Graphing data points, understanding slopes, rate of change.	Students will plot distance vs. time on a graph and use their data to analyze how quickly the object approaches or moves away from the sensor. By calculating the slope of the line on their graph, they can determine the rate of change, which is an introduction to concepts in calculus and algebra.

Sphero robots are programmable, round robots that can be directed by students along various paths. Such devices are particularly useful for the teaching of geometry, including the concepts of angles and distance measurement. The Sphero EDU platform offers a range of pre-made

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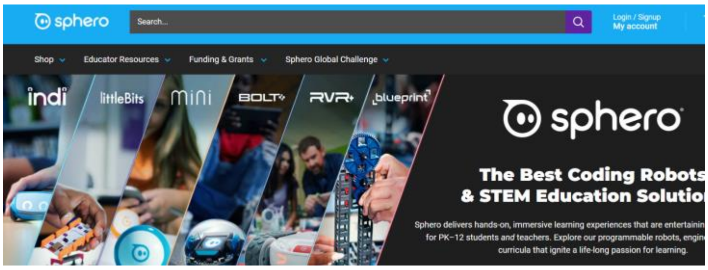
activities and content, providing educators with convenient tools for streamlined lesson planning.



https://sphero.com/

Integrating Sphero robots into math lessons can be an engaging way to make abstract concepts concrete. Here are some activities that leverage Sphero robots to teach a variety of math concepts (see Table 4).

Table 4 Activities with Sphero robots for Mathematics

Title of Activity	Activity	Math Skills	How It Works
Geometry and Angles	Students learn to calculate interior and exterior angles of shapes by programming the robot to turn at specific angles at each vertex.	Understanding angles, identifying polygons, measuring side lengths, perimeter, and area.	Have students use the Sphero EDU app to program the robot to trace specific shapes on the floor (e.g., squares, triangles, pentagons). They can calculate and set the angles and distances to create these shapes.
Patterns and Sequencing	Helps students recognize and create patterns, explore mathematical sequences, and test predictions.	Sequencing, pattern recognition, and series.	Program Sphero to follow a repeated sequence of movements (e.g., forward, turn 90 degrees, forward again) and observe the resulting path. Students predict the next steps based on the pattern.

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Area and Perimeter	Reinforces area and perimeter calculation through hands-on robot programming.	Perimeter, area, and geometry.	Ask students to program Sphero to create a closed path (e.g., rectangle, square). They calculate the perimeter by programming the robot to travel each side length and measuring the distance. For area, they can use their shape's dimensions
Fractions and Decimals	Students practice calculating fractional distances and translating these into programmed movements, enhancing their understanding of fractions in a real-world context.	Fractions, decimals, and parts of a whole.	Have students program Sphero to travel fractional distances of a predefined line or path. For example, program it to go 1/2, 1/3, or 1/4 of a given distance, allowing students to experiment with fractions and decimals.

Blue-Bot: An Educational Tool for Interactive Learning

The **Blue-Bot** robot, developed by **TTS**, is a programmable robot designed for children aged 4 and above, emphasizing foundational programming skills and early mathematics concepts. Equipped with Bluetooth connectivity, the Blue-Bot allows students to engage in coding tasks through direct input on the robot or via a companion app, fostering a hands-on approach to learning.

https://www.terrapinlogo.com/

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Educational Benefits:

- **Spatial Awareness and Geometry**: Students can program Blue-Bot to navigate predefined paths or grids, enhancing their understanding of spatial reasoning, angles, and distances.
- **Problem-Solving Skills**: By setting and debugging routes, learners develop critical thinking and algorithmic reasoning.
- **Collaboration**: The device supports group activities where students work together to achieve programming challenges, fostering communication and teamwork.

Key Features:

- Programmable through tactile buttons or a mobile application.
- Transparent casing that allows students to see the internal mechanics, sparking curiosity about engineering concepts.
- Integration with pre-designed mats, offering various challenges related to coordinates, sequencing, and mathematical reasoning.

mTiny: An Interactive Robot for Early Education

The **mTiny** robot from **Makeblock** is an interactive educational tool tailored for children aged 4-7, designed to introduce coding concepts and STEM fundamentals through play. Using a unique Tap Pen Controller, mTiny supports a screen-free coding experience that prioritizes kinesthetic learning.

https://images.app.goo.gl/T22mxxJgT59C3q8u6

Educational Benefits:

- **Mathematics and Logic Development**: mTiny's activity mats incorporate puzzles and tasks requiring pattern recognition, sequencing, and problem-solving.
- **Creativity and Storytelling**: Students use mTiny to explore narrative-based challenges, combining artistic and logical skills.
- **Interdisciplinary Learning**: Activities integrate literacy, art, and numeracy, creating a holistic learning environment.

Key Features:

- A screen-free interface promotes healthy learning habits and tactile interaction.
- Pre-designed map sets and challenges support educators in aligning tasks with curriculum goals.

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- A durable design that encourages hands-on experimentation and exploration.

Learning Management Systems (LMS) for Flipped Learning

In order to implement the flipped learning approach, educators require a platform through which to deliver pre-class content in an effective manner and to monitor students' progress. Some of the most effective tools include:

- **Google Classroom**: Google Classroom is a widely used, user-friendly platform that enables educators to upload a range of digital resources, including instructional videos, assignments, and quizzes. Teachers are able to organize content by units or topics, thus enabling students to access flipped learning resources independently.
- **Canvas**: Canvas is an LMS that incorporates a range of sophisticated features, including comprehensive video integration, assignment submissions, and assessment tools. Teachers may utilize Canvas to organize materials for a flipped learning approach, including instructional videos, practice quizzes and supplementary resources, thus enabling students to engage with the content in advance of the class.

Video and Content Creation Tools

In order to successfully implement the flipped learning approach, teachers will frequently be required to create their own instructional videos, in which they break down mathematical concepts that students can then study at home. The following tools are recommended for the creation of high-quality content:

- **Screencast-O-Matic**: This tool enables educators to record their screens and provide audio explanations, thereby facilitating the creation of instructional videos that guide students through mathematical problems or demonstrate the utilization of software for robotics programming;
- **Edpuzzle**: Edpuzzle represents a further development of the flipped learning approach, enabling teachers to incorporate questions directly into instructional videos. Teachers are able to upload their own videos or utilize existing content, incorporating interactive elements to facilitate student engagement with the material;
- **Camtasia**: Camtasia is a more sophisticated video editing tool that enables educators to produce videos of a professional and refined quality. The inclusion of features such as transitions, annotations and quizzes renders Camtasia an ideal tool for the creation of comprehensive, bespoke mathematical tutorials;
- **Khan Academy and YouTube**: It is not always necessary for teachers to create content from scratch. Video resources on a range of mathematical topics are available on platforms such as Khan Academy. Furthermore, YouTube offers a plethora of mathematical tutorials that educators may assign to their students for pre-class review.

Coding Platforms and Programming Languages

The teaching of programming is an integral part of the curriculum in robotics education. The introduction of students to the principles of computer coding also serves to enhance their logical and analytical thinking skills, which are of great importance in the study of

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mathematics. The following list provides examples of coding resources that can be employed in the context of a robotics-centred mathematics curriculum:

- **Scratch**: Scratch is a beginner-friendly programming platform that uses block-based coding, making it ideal for younger students. Teachers can design projects where students use math to control the movement and actions of virtual robots https://scratch.mit.edu/
- **Blockly**: Google's Blockly platform bears resemblance to Scratch and is frequently incorporated into robotics kits such as Wonder Workshop's Dash and Dot. Students utilize mathematical logic to control robotic movements, thereby reinforcing skills such as angle calculation, distance measurement and sequencing.
- **Python**: As students advance in their studies, Python becomes an indispensable programming language, particularly for robotics projects that entail more intricate calculations and algorithms. A considerable number of robotics platforms, including the Raspberry Pi, are compatible with the Python programming language, which makes it an invaluable tool for integrating advanced mathematical concepts.
- **RoboBlockly**: Specifically designed for the teaching of science, technology, engineering and mathematics (STEM), RoboBlockly allows students to code with block-based commands while learning fundamental mathematical concepts. Teachers may utilize RoboBlockly for mathematical programming challenges that are directly linked to robotics.

Assessment Tools

In a flipped classroom setting, assessment tools are of paramount importance, as they facilitate the monitoring of student progress and the provision of feedback to educators. The following represents a selection of the most effective tools for the assessment of student comprehension in an educational setting with a focus on robotics and the integration of mathematical concepts.

- **Quizizz:** The Quizizz platform allows educators to develop interactive, gamified assessments on mathematical concepts, which students can complete either before or after engaging in hands-on robotics activities. The platform provides immediate feedback and performance analytics, enabling educators to assess students' preparedness and proficiency.
- **Kahoot!**: Kahoot! is an optimal tool for conducting rapid, interactive assessments. Teachers are able to create quizzes pertaining to both mathematical concepts and robotics applications, which can be employed as introductory exercises or formative assessments to ascertain whether students have grasped the fundamental concepts before progressing to more sophisticated tasks.
- **Google Forms**: Google Forms provides educators with the capability to develop bespoke assessments comprising multiple-choice, short-answer, or open-response questions. Teachers are able to embed mathematical problems or questions pertaining to the logic of coding in robotics, with responses automatically graded or reviewed for deeper insights.

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Robotics and Math Curriculum Resources
The utilization of pre-existing curriculum resources has the potential to reduce the time required for lesson preparation and to provide structured, standards-aligned lessons that integrate robotics and mathematics.

- **STEMfinity**: This online platform provides a variety of robotics kits, STEM materials, and curriculum guides. Teachers can access pre-prepared lesson plans that integrate robotics into mathematics education, thereby saving time and ensuring alignment with learning standards https://stemfinity.com/
- **TeachEngineering**: TeachEngineering offers free, standards-aligned K-12 engineering curricula, including robotics activities that incorporate mathematical concepts. These resources enable educators to access lesson plans and student handouts for robotics activities that reinforce mathematical skills https://www.teachengineering.org/

Strategies for active learning and collaboration

The integration of robotics into mathematics education provides an opportunity for a multifaceted, experiential approach that fosters active learning and collaborative engagement. As students engage with robots to address mathematical problems, they not only enhance their comprehension of mathematical principles but also cultivate critical thinking, teamwork, and problem-solving abilities. However, fostering active engagement and collaboration in a robotics-focused mathematics class necessitates the implementation of specific strategies to guarantee that students fully capitalize on these opportunities. This article delineates practical strategies for educators to nurture active learning and effective teamwork within the classroom.

1. Set Clear Objectives with Real-World Relevance

One of the best ways to foster active learning in a robotics-centered math classroom is to start each activity with clear, real-world objectives. When students understand the purpose of each activity and see its practical applications, they are more motivated to engage actively:

- Link to Math Standards: Clearly connect each robotics activity to specific math skills and standards, so students see how their robotic tasks reinforce classroom learning goals. For instance, if they are learning about angles, have them measure and calculate rotations for their robot to move through a set path;
- Create Math-Based Scenarios: Frame each robotics activity around a real-world challenge that requires math skills. For example, create a scenario where students need to program a robot to navigate a maze based on angles and distance calculations, simulating an obstacle course or delivery route.

2. Embrace a Problem-Based Learning (PBL) Approach

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Problem-based learning transforms the classroom into a collaborative space where students work together to solve real-world challenges. Robotics projects are ideal for PBL, as students must use critical thinking and mathematical problem-solving to achieve their goals:

- Encourage Iteration: Emphasize that engineering and problem-solving often require multiple attempts. Allow students to test their robots, learn from failures, and improve their designs. This fosters a growth mindset, where students understand that learning is a process;
- Present Open-Ended Challenges: Rather than giving students a step-by-step guide, present them with an open-ended problem. For example, ask students to design a robot that can measure distances accurately, then challenge them to use algebra and geometry to achieve precision.

3. Organize Students into Collaborative Teams with Assigned Roles

Collaboration is essential in a robotics classroom, and assigning roles within teams can help each student take ownership of their contribution. For instance, roles might include a "programmer" to handle coding, a "mathematician" to calculate angles and measurements, a "designer" to build and assemble the robot, and a "tester" to evaluate functionality:

- Create Team-Based Reflection Routines: After each session, have students reflect on their team's progress, discussing both individual and group contributions. This encourages accountability and communication, both essential for effective teamwork;
- Rotate Roles: To ensure all students engage with different aspects of the project, rotate roles periodically. This helps students develop a diverse set of skills, from math calculations to programming and critical thinking.

4. Utilize Flipped Learning to Prepare Students for Hands-On Activities

Flipped learning—where students review foundational content at home before applying it in class—works exceptionally well for robotics activities. By learning basic math concepts in advance, students arrive ready to dive into practical applications:

- Use Online Quizzes to Gauge Readiness: Assess students' understanding with a quick online quiz after they complete their pre-class work. This helps you determine if additional review is necessary and ensures students are prepared to actively participate in the in-class robotics activities;
- Assign Pre-Class Videos or Simulations: Provide instructional videos or math-related simulations that introduce key concepts. For example, if students will need to calculate angles, share a short video on trigonometric functions that they can watch before class.

5. Incorporate Peer Teaching and Learning Opportunities

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Peer teaching is a powerful way to reinforce learning, as explaining concepts to others deepens one's understanding. Encourage students to teach each other specific mathematical concepts or robotics techniques:

- Encourage Pair Programming: In programming, pair students up and have one student write the code while the other reviews and verifies calculations. This approach fosters discussion, ensures accuracy, and promotes a collaborative learning environment;
- Set Up "Expert" Stations: Assign students who excel at specific skills (e.g., calculating rotations or coding specific commands) to act as "experts." These students can rotate among groups, providing guidance on math calculations or programming issues, which strengthens their knowledge while supporting their peers.

6. Design Reflection Activities to Reinforce Mathematical Thinking

Reflective activities help students connect their robotics experiences to mathematical principles, reinforcing the skills they're practicing:

- Post-Project Analysis: After completing a project, ask students to present their work to the class, explaining the math they used and how it helped solve the robotics challenge. These presentations encourage students to take pride in their work and allow them to learn from each other's approaches;
- Math Journals or Logbooks: Have students maintain a log where they record the math they applied during each session, such as distance calculations, angle measurements, or timing intervals. These logs encourage students to articulate their thinking and provide a written record they can review later.

7. Use Gamification to Foster Engagement and Collaboration

Gamifying robotics challenges adds an element of fun and motivates students to work together toward common goals. Here are a few ways to add friendly competition to your classroom:

- Leaderboard Challenges: Set up challenges where teams earn points for completing specific tasks, such as calculating precise angles for a robot to navigate a maze. A leaderboard can add excitement while reinforcing the need for accuracy and collaboration;
- Timed Missions: Have students complete robotics missions within a set time. For instance, they might need to calculate the correct speed and distance for their robot to reach a goal within a time limit. This requires quick, collaborative problem-solving and reinforces math skills under time constraints;
- Level-Based Achievements: As students complete tasks or reach milestones, award them "level-ups" or badges. For instance, they could earn a "Geometry Genius" badge for calculating and programming accurate angles or a "Measurement Master" badge for precise distance calculations.

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8. Integrate Digital Tools for Real-Time Collaboration

Digital tools can support active learning and collaboration in robotics projects, particularly if students are working in different groups or locations:

- Google Workspace for Team Planning and Documentation: Google Docs, Sheets, and Slides are great for team collaboration. Students can document math calculations, share design plans, or draft a project presentation, enabling everyone in the group to contribute;
- Virtual Robotics Platforms for Practice: Virtual robotics simulators like VEXcode VR or Tinkercad allow students to practice programming and math calculations virtually. These tools are especially useful if in-person robotics time is limited, as they give students a way to apply math concepts in a simulated environment;
- Collaborative Coding Platforms like GitHub or Repl.it: For more advanced robotics projects, platforms like GitHub or Repl.it let students work collaboratively on code in real time, supporting complex programming challenges that reinforce logical and mathematical thinking.

9. Facilitate Regular Peer Feedback and Group Reflection

To build a collaborative culture, create routines for peer feedback and group reflection, allowing students to share insights and learn from each other:

- Peer Evaluation Forms: After each project, have students fill out peer evaluations, providing constructive feedback on teamwork and individual contributions. This fosters accountability and encourages students to reflect on their collaborative skills.
- Reflective Group Discussions: Set aside time for groups to discuss what worked, what didn't, and what they learned. Guide students in focusing on both math-related takeaways and teamwork dynamics, helping them build both math and interpersonal skills.

Conclusion

The integration of robotics into mathematics instruction represents an innovative and impactful approach to teaching core mathematical skills and knowledge. By following principles of hands-on learning, problem-solving, interdisciplinary connections, visualization, collaboration, and iterative learning, educators can create a dynamic learning environment that engages students and deepens their understanding of mathematics. The incorporation of robotics in mathematics education has the potential to foster a generation of learners who

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not only excel in mathematics but also appreciate its practical applications in the world around them.

The integration of robotics and flipped learning into mathematics education presents a range of benefits for educators, including increased student engagement and understanding, more efficient use of class time, and enhanced professional development. This approach effectively transforms the traditional classroom into a dynamic and interactive learning environment that is conducive to the flourishing of both students and teachers. By adopting robotics and flipped learning, teachers are not only enhancing their students' mathematical abilities but also establishing themselves as leaders in the evolving field of education.

The integration of robotics into mathematics instruction through the flipped learning approach provides a robust, experiential methodology that facilitates enhanced comprehension of intricate concepts among students. The appropriate combination of robotics kits, content creation tools, coding platforms, assessment resources and structured curriculum guides enables teachers to transform their classrooms into interactive environments that foster both curiosity and mastery. By investing in these tools and resources, educators can establish a mathematics classroom that is focused on robotics and is engaging, innovative, and successful in helping students develop essential mathematical and problem-solving skills.

Active learning and collaboration are fundamental aspects of a mathematics classroom that incorporates robotics. They permit students to engage with mathematical concepts in a meaningful and practical manner. The implementation of these strategies, which encompass the formation of collaborative teams, the utilization of flipped learning and gamification, can facilitate the creation of a dynamic learning environment wherein students engage actively, assume ownership of their learning and provide mutual support in the pursuit of shared objectives. When implemented effectively, robotics can serve as an invaluable tool for not only enhancing mathematical understanding but also fostering essential 21st-century skills such as critical thinking, problem-solving, and teamwork.

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