EUROPEAN JOURNAL OF STEM EDUCATION

European Journal of STEM Education,
2026, 11(1), 13
eISSN: 2468-4368

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Research paper

Project-Based Learning during Scientific Student Exchanges Using Arduino

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Citation: Pesthy, S. G., Hömöstrei, M., & Jenei, P. (2026). Project-based learning during scientific student exchanges program using Arduino. *European Journal of STEM Education, 11*(1), 13. https://doi.org/10.20897/ejsteme/18049

Published: March 8, 2026

ABSTRACT

Student exchange programs are popular worldwide and may offer an opportunity to enhance STEM education by tapping into students' enthusiasm for learning languages and experiencing foreign cultures. Additionally, this kind of projects may foster gender-equality in STEM subjects according to our literature review. This study investigates the impact of a Hungarian-German STEM-focused exchange program on high school students' knowledge and attitudes towards physics through project-based learning. Over two consecutive years, a group of actual 9th grader Hungarian and 8th grader German students collaborated to build an Arduino-controlled electric car. Pre- and post-tests were conducted to measure knowledge gains across Bloom's taxonomy, along with attitude surveys. Results showed significant improvements in students' knowledge regardless of nationality, with a large effect size, indicating the program's effectiveness. While Hungarian students initially lagged behind their German counterparts, the gap closed after targeted preparatory sessions were introduced in the second year. This collaborative learning environment fostered equity in knowledge acquisition. The findings suggest that student exchange programs with a focus on STEM subjects can be effective in improving knowledge and attitudes towards science and technology. These findings encourage us to develop a "STEM–AI–IoT-based cross-cultural project learning" model.

Keywords: experimental study, physics education, project-based learning, Arduino

Student exchange programs are popular among secondary school students worldwide (Sustarsic, 2020). By organizing a STEM (science, technology, engineering and mathematics) exchange programs we aim to put students' enthusiasm for language learning, learning about foreign cultures and travelling at the service of STEM education. Furthermore, by organizing the STEM exchange program, we aim to reduce the gender gap in STEM fields.

In this article, a series of one-week exchanges are presented within the framework of a Hungarian-German exchange program, which aims to motivate students towards science and technology and to develop their knowledge of physics (mainly electromagnetism and mechanics) and engineering. During the four workdays of the exchange project, the student's task was to use an Arduino microcontroller to build an electric car, that can detect a wall, then emit a light or sound signal, and turn.

The article includes the results of two out of three consecutive years of knowledge measurements and attitude tests as well as their discussion. Our program was based on the project-based learning (PBL), which we made collaborative through developments in the third year.

The literature review highlights a critical gap in STEM education: To the best of our knowledge, only one study has yet researched the effects of high school scientific student exchange programs, which can prove to be a useful instrument for approaching gender equality in science and engineering.

Research questions

The primary objective of this paper is to evaluate the efficacy of exchange programs based on Arduino and Project-based Learning (PBL) in enhancing students' knowledge and motivation. This can serve as a basis for establishing a STEM–AI (Artifical Intelligence)–IoT (Internet of Things)-based cross-cultural project learning model and for examining the impact of such programs on gender equality in scientific and engineering careers.

The present study thus seeks to address the following research questions:

- RQ1. The central question guiding this study is whether the Arduino-supported project can enhance students' knowledge, and if so, whether this enhancement can be achieved at higher levels of Bloom's taxonomy (see later H1 and H3).
- RQ2. It is imperative to ascertain whether the project can indeed serve to enhance students' motivation to pursue careers in STEM fields (see later H2).
- RQ3. A further research question concerns the extent of any discrepancy in prior knowledge between pupils from schools in the two countries and the feasibility of eliminating this discrepancy (see later H4).

LITERATURE REVIEW

STEM projects in informal learning environments can be divided into seven themes: inquiry, focus on problems, design, cooperative learning, student-centered, hands-on, and 21st-century skills (Hussim et al., 2024). According to this classification our project is a "project based" activity.

Project-based learning and STEM pedagogy

PBL is a specific approach to a learning environment that relies heavily on learner activities. PBL consists of five key steps: (1) posing a real-world problem (2) planning and conducting a contextualized inquiry (3) collaboratively seeking solutions to problems, which mirrors the process of solving real-life challenges (4) evolving the project, and (5) creating concrete products to solve the central problem and sharing them with other groups (Sawyer, 2014).

In STEM subjects, context-based learning provides a good opportunity for students to learn not only scientific concepts but also their real-world-applications (King & Henderson, 2018). Context-based learning is well supported by PBL (which includes planning, creation, processing and evaluation (Diana et al., 2021). PBL is product-oriented, therefore students produce physical and, where appropriate, functional objects. University surveys have shown that students enrolled in a maker course were more likely to maintain a positive attitude towards STEM-subjects (Lyon et al., 2023). Another argument in favor of using PBL is the efficiency-enhancing effect of student collaboration (Girwidz et al., 2019; Benschop & Husu, 2021). In our case, we utilised the increasing presence of self-driving vehicles to spark interest with real-world applications and created a collaborative learning experience by creating a fully functional Arduino powered car.

It is evident that current research in the field of STEM education places significant emphasis on the enhancement of girls' engagement, motivation, and opportunities, given the persistent underrepresentation of women in these disciplines (Awoniyi & Jokotagba, 2025; Dogutas, 2025). In Colombia, a research group has created a laboratory box with the aim of combating the stigma surrounding STEM careers and of motivating girls. The box is based on the integration of Colombian ancestral Pacific traditional knowledge and biochemistry engineering. The project garnered significant participation, with over 400 girls taking part. A notable finding was that 70% of participants expressed a firm intention to pursue careers in science or engineering, after engaging with the program. (Donneys et al., 2024). Among first-year undergraduate students, a project-based engineering course focusing on design has been shown to have a positive impact on engineering attitudes, especially in the area of self-efficacy, as well as on the development of professional skills. The research also showed that female participants benefited more from participating in the project than male participants (Sperling et al., 2024). However, it has been demonstrated that STEM activities do not invariably engender equivalent levels of motivation in males and females with regard to pursuing STEM careers (Ribeirinha et al., 2025). Consequently, it is imperative to direct particular attention to this aspect when formulating projects. The impetus for our research stemmed from the notion that, in order to mitigate the gender disparity, we sought to integrate the STEM project into a student exchange program that would be more appealing to women.

At present, research in the field of STEM education is focusing on the use of AI to enhance knowledge transfer and boost student motivation. In the domain of mathematics and computer science education, for instance, the development of AI-powered tutoring systems has been undertaken to provide personalised feedback and assist students in problem-solving (Sein Minn, 2022; VanLehn, 2011). In the case of natural sciences, AI-based virtual laboratories have been developed (Sapriati et al., 2023). In addition, it has been shown in engineering education in the field of thermodynamics that the use of AI helps to overcome students' misconceptions (El Fathi et al., 2025). A recent meta-analysis has indicated that the integration of AI in STEM education at the secondary level has a substantial positive impact on students' affective and cognitive development in the majority of cases (Akhmetova et al., 2025). This underscores the importance of incorporating AI into such projects, despite the fact that, due to the rigorous selection criteria, the analysis ultimately identified only eight of the original 188 articles as being worthy of further investigation (Schefers, 2026).

Applications of Arduino in STEM education

Over the last decade, Arduino has been increasingly used in primary, secondary and academic school practice, mostly to support STEM projects, (García-Tudela & Marín-Marín, 2023) often through robotics projects. The aim of its use is usually two-fold: to help students understand and acquire scientific concepts, and to increase their interest in science and engineering (Acar et al., 2025).

Arduino, a low-cost, open-source microcontroller, provides students with the opportunity to solve real-world problems and build real, working, and possibly useful devices. By doing so, they can experience Research and Development, creation, experimentation, and gain experience in programming and electronics. Although Arduino is considered a cheap microcontroller, in many cases the barrier to its use is that educational institution cannot afford the necessary equipment for the project (Christidou et al., 2022). Therefore it is important to design projects to ensure that as few tools as possible are used.

The idea of building functional tools with students is not new. A pilot study with 25 students, for example, tested eight learning activities in which students were asked to solve real-world problems using Arduino, and found that students' knowledge and interest in programming and technology increased (Rossano et al., 2020). In many cases, teachers or students make inexpensive tools to demonstrate interesting, otherwise difficult, or expensive experiments (Gingl et al., 2019), whether in mechanics (Espindola et al., 2018; Van Bien & Hai, 2019), optics, acoustics (Vitkóczi & Piláth, 2020), electromagnetism (Galeriu et al., 2015; McCaughey, 2017; Schnider & Hömöstrei, 2023a), or astronomy (Schnider & Hömöstrei, 2023b).

Another advantage is that there are many solutions available on the internet, so students can develop independently, although the abundance of amateur-created online solutions can lead to misuse or misunderstanding, especially in an educational context. To counter this, the focus should be on teaching correct principles, encouraging independent problem-solving, and using well-designed case studies to build technical competence and thoughtful engineering practices (Makan et al., 2019).

The projects most closely aligned with our research involved projects in which students worked with Arduino, usually during camps, workshops or laboratory exercises. Shang et al. (2023) investigated the development of self-efficacy and computational thinking in rural elementary students during a three-day robotics STEM camp. They found that both self-efficacy and computational thinking skills of participants improved as a result of the project.

Alò et al. (2020) used Arduino with underprivileged students in Chile. Although they found no detectable improvement in students' attitudes, they found that students needed more interactive experiences, which Arduino is an excellent way to provide. The results of their questionnaire survey also showed that students had a positive predisposition to the use of new technologies to learn science. At the Universty of La Verne, a series of Arduino-projects were developed to increase the interest of non-physics/astronomy students in physics, which proved to be very successful in enhancing students' attitudes (Chaudry, 2020). In a study of 16 students from a small liberal arts college using Arduino to teach electricity, the enthusiasm and engagement of the participants increased (Smith, 2023). Arduino has been used successfully in secondary school projects such as ours. For example, at Székely Mikó College in Sfântu Gheorghe, students used the microcontroller to carry out various measurements in a 'Scientists Club' (Pető, 2019). At Aeronautical University in Prescott, Canada, a five-day science camp was created for high school students using an Arduino electronics kit. During the project, two tests were used to measure student satisfaction with and achievement of the program's goals (Post, 2016). In addition, a study of candidate teachers showed that Arduino can also be used to develop students' algorithmic thinking (Sarı et al., 2022). Robotics can provide an excellent opportunity to incorporate STEM education (Kim et al., 2015) and offers a platform for the integration of STEM education for learners (Barak & Assal, 2018). Considering that, Arduino is a versatile electronics tool, we used it to increase the students' knowledge and enthusiasm for physics (Bicer et al., 2020).

Theoretical framework

Student exchange in support of STEM education

The term "scientific student exchange" is utilised in a variety of ways within the extant literature. The term typically refers to three distinct categories. Firstly, high school students who visit universities and work alongside researchers or university students (Cramer et al., 2015; Kitchen et al., 2018). Secondly, university or college students who visit other universities or different departments within the same university (Black et al., 2022; Hardiman et al., 2022; Jaiswal et al., 2024). Less commonly, the term is used to refer to combining a traditional student exchange program with a STEM project, but in these cases, the focus is primarily on developing the cultural competencies of STEM students (Traum et al., 2024). We found only one study examining the impact of secondary school exchange programs on changes in STEM knowledge and attitudes, which found that the exchange program they created had a positive impact on students' relationship with STEM (Wolfe, 2023). This result highlights the need for further research on the subject.

Students' attitudes towards STEM careers vary widely. A promising way to promote STEM careers is to enhance students' perceived ability to succeed in fields they do not appeal to (Rosenzweig & Chen, 2023). An exchange program can provide students with opportunities to become involved in these activities and experience success. University exchanges have a higher participation rate among women (Benedictis & Leoni, 2020) whereas engineering careers are preferred more by boys (Rosenzweig & Chen, 2023), the tendency to which, importantly, begins well before university (Master et al., 2021). STEM-focused exchange programs for highschool students can balance the presence of genders by using the popularity of exchanges among girls, inspiring more of them to pursue an engineering career (Banton et al., 2024). Based on this, science-based student exchange programs in high schools can help move towards gender equality in both fields. In addition, our project included ICT (Information and Communications Technology), which has been shown to reduce the gender gap in mathematics education (Salami & Spangenberg, 2024).

Bloom's taxonomy

Bloom's taxonomy provides a theoretical background for the knowledge testing methodology. To determine the depth of mastering certain knowledge items, knowledge assessment test questions were adapted to measure the following knowledge levels: remember, understand, apply, analyze, evaluate and create (Krathwohl, 2002)

We used this taxonomy to relate the questionnaire items to specific levels of knowledge and to understand how much progress was made at each level. Questions were assigned to knowledge levels according to the recommended question types of the revised Bloom's Taxonomy (Anderson et al., 2001).

The Bloom's taxonomy was successfully used in plenty of different science methodological researches, such as Millet et al. (2024), who used it in designing an online climate change class, using a method called 'backwards design', similar to ours, whereby the design first focuses on the intended outcomes of the course or lesson, followed by making decisions about how to assess understanding, then outlining the goals needed to achieve the desired outcomes and constructing the most appropriate learning activities (Wiggins & McTighe, 2005). In this process, we first identified the required learning outcomes, decomposed the knowledge to be transferred into items, and then used these items to design the assessment tool (knowledge measurement questionnaire) and learning process (the actual project). Compared to Millet et al., who used several testing methods to assess the changes in knowledge levels, we measured all levels simultaneously in a pre- and post-test, owing to the short time available.

Previous research has separately investigated the effectiveness of PBL and Bloom's Taxonomy-based learning (the latter implies that special attention is paid to ensuring that students are exposed to sub-tasks at higher knowledge levels when planning learning activities)(Charoenphol & Bandyopadhyay, 2024). In our study, we combined these two teaching methods to achieve better results (Huysken et al., 2019).

Collaborative learning

Cooperative learning is a student-centred instructional strategy, in which learners co-create understanding through interaction, shared goals, and coordinated problem solving.

Empirical syntheses consistently demonstrate that well-structured collaborative approaches—such as Johnson and Johnson's cooperative learning model or Slavin's evidence-based group methods—improve academic achievement, motivation, and peer relations compared to individualistic learning environments (Johnson & Johnson, 2009; Slavin, 2014). Critical design features such as positive interdependence, individual accountability, and explicit support for exploratory talk have been shown to facilitate deeper conceptual understanding and higher-quality group reasoning (Waring, 2002). These principles are especially relevant in engineering-oriented STEM contexts, where tasks require distributed expertise, iterative troubleshooting, and shared decision-making;

research on computer-supported collaborative learning further highlights how joint problem representation and group cognition enhance project-based technological learning (Hmelo-Silver & Barrows, 2008; Stahl, 2006).

Combining PBL with collaborative learning has a positive impact on students (Baser et al., 2017; Chu et al., 2011). Therefore, during the third year, PBL was complemented with collaborative learning techniques, to force students to rely on each other, to help each other, and to explain, so that mutual regulation or even disagreement could occur which, according to research, generates a positive cognitive process in terms of deepening knowledge (Baser et al., 2017; Hron & Friedrich, 2003)

HYPOTHESES

- H1. The project can achieve a significant increase in students' knowledge, irrespective of their nationality.
- H2. The project motivates students from both countries towards STEM fields
- H3. The project developes students' knowledge at all levels of Bloom's taxonomy.
- H4. The methodological improvements (making the project collaborative) that we introduced between the two projects cause a significant change in students' progress.

METHODS

Sample

The sample consisted of 15 eighth-grade German and 15 ninth-grade Hungarian students both years (**Table 1**). There was no overlap between the students involved in the two projects. In the third year of the project, one German student did not submit a post-test, therefore this year we only analyzed pre-post and attitude-test data from 14 German students.

It is important to note that the German high school is a science-oriented institution. Consequently, our German students were initially more engaged and accumulated more experience in science projects. The Hungarian high school is characterized by a strong emphasis on humanities subjects, which results in Hungarian students possessing comparatively limited prior knowledge.

To remedy this, during the third year of the exchange program, we held a four-lesson preparatory course (one hour each) for Hungarian students during the month before the project to avoid demotivating them by failure when working with German students. During these sessions, we also strengthened their language skills and prepared them for unexpected situations that might arise during the project (for the entire project-series outline, see **Figure 1**).

Procedure

The project involved students using the Arduino for approximately four hours a day over four days. These days, the sessions took place in the morning, followed by lunch and various leisure activities (a visit to the ELTE laboratory, a city quiz in the Buda Castle, a boat trip on the Danube and a visit to the Parliament). The main objective of the project week was to build a car that stops, flashes lights and sounds when it detects an obstacle and then turns. The preparatory phase of the project provided students with the knowledge they needed to complete the project (see **Table 2**).

Each time the material was processed, introductory repetition was used (e.g., a short quiz). Simpler models were used to illustrate the theoretical background, with a focus on practical applications. Afterwards, students worked in groups on playful exercises to memorize their knowledge better. The task sheets played a key role in guiding the sessions and consisted of four parts: introduction to physics, assembly, basic task (carried out by students based on a description) and creative tasks (which required the application of previous knowledge), which helped the students to work independently (see **Figure 2**). The project phases are presented in **Table 2**.

In the first and second years, we used non-collaborative tasks to teach new material, which resulted that in one member (usually the more experienced German student) doing the majority of work in many pairs. Therefore, methodological improvements were made in the third year: Hungarian and German students attended to separate introductory lectures, and their task sheets were structured differently. To complete the task the students had to teach each other what they had learned in the introductory lecture.

Before beginning the tasks, it was always decided which member would be the programmer and which would be the builder, so the programmers always had to learn programming knowledge from their partners.

Table 1

The number of groups in the two years presented in the article and the method used in each year

Group	Project year	Nationality	N	Method
1	2nd	German	15	PBL
2	2nd	Hungarian	15	
3	3rd	German	14	Collaborative PBL
4	3rd	Hungarian	15	

Figure 1

The whole project process. This article presents the results of the second two years. The sub-processes in which students from the two nations participated separately, in their own countries, are shown in separate columns

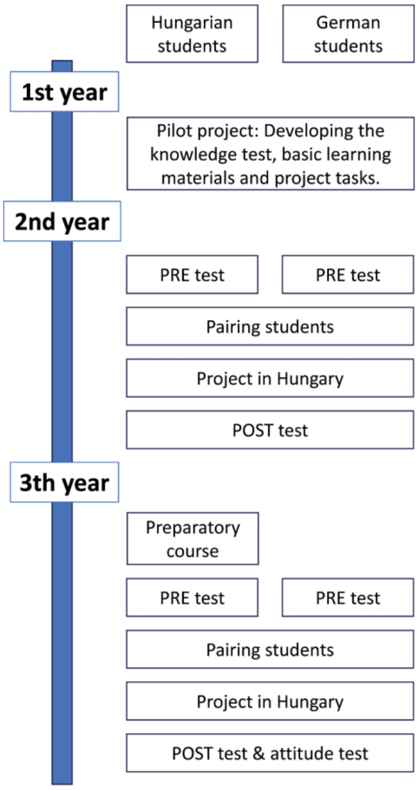


Table 2

The implementation of the phases of project-based learning in research. The first column shows the phases of the project method, while the second column shows their implementation in our project

Project stage	Student activities
Providing a situation	Introducing the self-driving cars.
Preparatory phase	Learning about all the devices involved (sensor, motor, H-bridge...) • Day 1: LED (light emitting diode) handling, learning about the system, creative exercise: making a traffic light and police siren, physics of ultrasonic distance measurement • Day 2: Distance measurement, transistor basics, motor control with transistor • Day 3: Operation of the H-bridge (an electronic circuit allowing the engine to rotate in both directions), motor control with H-bridge, car assembly
Planning the project	Implement the "basic task" - the car giving a signal and turning away at the wall (in the basic project the circuit included an Arduino board, an H-bridge, two motors, an ultrasonic distance sensor and an LED or speaker). Any errors that were visible during testing were corrected by the students.
Evaluation of the project	Choose from extra tasks (such as following a line painted on the ground or reading a traffic light with a colour sensor).
Reporting and recording	On the last day, the students were given a reporting and recording session where the pairs presented their completed cars

Figure 2

The construction of the cars (left) and the oral presentation (right)

Instruments

Testing the effectiveness of knowledge building

We used pre- and post-testing to assess the effectiveness of our methodology in achieving our knowledge transfer objectives. As described earlier, the questions were adapted to each level of Bloom's taxonomy to track changes at each level of knowledge.

The pre-test contained 20 questions, and the post-test contained 22 questions. The majority of the questions (17 questions) were identical in the pre and post-test to ensure comparability. During the analysis, it was necessary to exclude one question from the test because the online test software did not ask it to some students due to an unknown error.

The rationale behind the variation in the number of questions pertained to the experience of previous years, where students demonstrated an inability to respond to high-level questions at the beginning of the project. Consequently, these questions were excluded from the pre-test. Some of these questions were replaced in the pre-test with more questions at lower knowledge levels or basic physics and mathematics.

Consequently, the overall scores of the two tests were not exactly the same; therefore, the percentages obtained by the students were used for the evaluation. Thus, the pre-tests were slightly easier than the post-tests, but this did not affect the comparability of the groups. The comparability of the pre- and post-tests was also not affected by this method because, in the worst case, no significant increase in knowledge between the two tests was found even if only the overlapping questions show this difference. However, the advantage of the method is that both tests provide sufficient data for the evaluation. The questionnaire is shown in the Appendix (**Table 5**).

Satisfaction and attitude change testing

Student satisfaction was measured in the third year using a questionnaire that was completely independent of the knowledge measurement. This was expected to provide comparable results between Hungarian and German students which could be used for statistical measurements.

The role of these questionnaires was largely to test whether our aim of promoting science and technology was met. In the course of developing the questionnaire, we utilised the questionnaire made by Post (2016) as the foundational framework.

The questionnaire consisted of three parts:

1. Overall satisfaction, rating of facilitator(s) and background: scale 1 (very dissatisfied) to 6 (very satisfied)
2. Evaluation of the use of Arduino and the tasks: 1 (very dissatisfied) to 6 (very satisfied)
3. Feedback on the programme (explanatory answers).

Overall, the aim of testing participant satisfaction was to improve the specific program of the project, but we do not necessarily link effectiveness to satisfaction. In this questionnaire, one question (see Q12 in **Table 4** in Appendix) on the improvement of students' attitudes towards science was used for measuring the effectiveness of the project.

Data collection

Students in both years completed pre-test before the project and the post-test immediately after the project presentations. In the last year, they also completed the satisfaction and attitude questionnaire at the same time as the post-test.

In the pilot year (not detailed in this paper), a control group was meticulously selected from among students in the same grade who did not participate in the project, with this selection being made on both the Hungarian and German sides. It was determined during the pilot year that the control group did not encounter the topic in question during their school studies during the week of the project (Pesthy & Hömöstrei, 2017). As a consequence of this finding, it was decided that a control group would not be utilised in the subsequent years of the project. It is evident that this presents a challenge in terms of generalizing the results, as will be discussed later.

Data analysis

In the case of the knowledge test, we ran a multivariate analysis of variance (MANOVA) on the data of the four groups to detect possible differences between Hungarian and German students within the project, as well as differences between years. The latter is necessary to demonstrates the effects of methodological improvements. We ran a Shapiro–Wilk test to check whether we could use parametric tests on the group data. Tukey's correction was then used for post-hoc testing.

The results of the questions were also examined (within the same MANOVA) by summing them at Bloom's taxonomy levels. For the data summarized by level, post-hoc testing was used to examine whether significant increases in students' knowledge were achieved at each level over the course of the project.

In the case of the satisfaction and attitude test, to detect the differences between German and Hungarian students (due to the lack of normality of the data), a Mann-Whitney test was run for all questions. All statistical analyses were performed using JASP version 0.18.0.0.

RESULTS AND DISCUSSION

Examination of reliability and validity

In order to ensure the validity of the knowledge test, the knowledge to be transferred during the project was divided into items and the individual questions were formulated in relation to these items. The subsequent stage of the research process involved a discussion of the questionnaire with in-house experts, who were instrumental in its development. However, a quantifiable validity test was not performed.

Following the experiences of the pilot year, the knowledge assessment questionnaire was further developed. The reliability of the test was determined by examining the Cronbach's alpha value of the completed test. In the case of the pre-test, this was 0.588, which did not reach the usual acceptance level, while in the case of the post-test, it was 0.794, which was deemed acceptable.

The low Cronbach's alpha value of the pre-test can be explained by the fact that in this case, the students had very little prior knowledge of the subject. This can result in (1) the variance of the pre-tests being low, which reduces Cronbach's alpha, and (2) students probably chose answers at random for the multiple-choice questions. This second problem also can couse a lower alpha value.

It is also important to note that the tests are not homogeneous constructs. Some of the questions test knowledge about physics, while others test programming knowledge, and relate to different levels of knowledge. This inhomogenity also can reduce the Cronbach's alpha value (Edelsbrunner et al., 2025a, 2025b).

A reliability test for the attitude and satisfaction test was not performed, as the results were not intended to be used as a scale. Instead, the results were interpreted on a question-by-question basis.

Testing the effectiveness of knowledge building

Main effects

For the projects in both the 2nd and 3rd year, all tests of all groups showed a normal distribution according to the Shapiro-Wilk test therefore, a MANOVA was run on the pre- and post-test results of the Hungarian and German groups in both years at different knowledge levels. The mean and standard deviation of each test are shown in **Figure 3**.

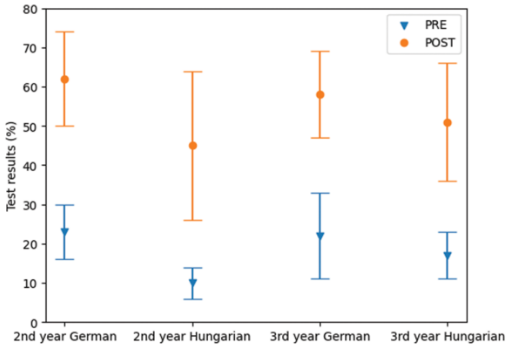
The results of the analysis showed that there was a significant difference between the pre- and post-tests regardless of year and nationality (pre-post main effect: $F(1, 110) = 318.762$ $p < 0.001$ $\eta_p^2 = 0.743$), this suggests that the intervention was effective on students' knowledge regardless of all factors.

Regardless of the year, there was a significant difference between nationalities, with a large effect size (main effect: $F(1, 110) = 18.286$, $p < 0.001$, $\eta_p^2 = 0.143$). In other words, German students performed better overall during the project.

In contrast, no significant difference was found between years (timing main effect: $F(1, 110) = 0.439$, $p = 0.509$, $\eta_p^2 = 0.004$). This means that their knowledge improved from the pre- to post-tests in both years.

Figure 3

Pre- and post-test results of the Hungarian and German groups in the 2nd year and 3rd year project. Error bars showing the standard deviation of the data



Pre-test comparison

For deeper understanding, we used post-hoc tests (with Tukey's correction). There was no significant difference between the Hungarian and German groups in the pre-test in 2nd year ($p_{tukey} = 0.129$) or 3rd year ($p_{tukey} = 0.980$).

In the pilot project, we found a significant difference between the pre-tests of the Hungarian and German students (Pesthy & Hömöstrei, 2017). The disappearance of a significant difference between the Hungarian and German groups in the pre-tests in the 2nd year is surprising. Based on the results of the pilot project, we would have expected the significant difference in performance of German and Hungarian students to disappear only in the 3rd year of the project, due to the preparatory work we begun that year.

This result enables a comparison between groups in post-tests; however, it also hinders the demonstration of the effect of preparatory work when considered in isolation from other effects.

Pre-post test comparison

There was a significant difference between the Hungarian participants' pre- and post-tests in the 2nd year ($p_{tukey} < 0.001$) and 3rd year ($p_{tukey} < 0.001$). In the German group, there was also a significant difference between the pre- and post-tests in both years ($p_{tukey} < 0.001$ for the 2nd year and $p_{tukey} < 0.001$ for the 3rd year).

The repeated measures MANOVA allowed us to examine individual levels of knowledge within the framework of interaction analysis. The means and associated variances for each knowledge level on each test are presented in **Figure 4**, and **Table 3**.

Table 3

For each year and nationality, the ptukey values associated with the interactions are shown. Significant differences between pre- and post-test are indicated by asterisk. In italics are the data for which the pre-test did not contain a question i.e. only the deviation from 0 was examined

Level	2nd year		3rd year	
	German	Hungarian	German	Hungarian
Remember	0.055	<0.001*	0.012*	0.075
Understand	<0.001*	0.597	0.209	1.000
Apply	<0.001*	<0.001*	<0.001*	<0.001*
Analyse	0.006*	<0.001*	1.000	<0.001*
Evaluate	<0.001*	<0.001*	<0.001*	<0.001*
Create	<0.001*	0.002*	<0.001*	0.074

Relatively smaller increases were achieved in lower levels of knowledge, such as remembering and understanding, on one hand this was probably because students already performed better at these levels in the pre-test and the programme focused less on getting students to learn the theory and more on getting them to apply it. Therefore, it is not surprising that there is generally a greater increase at the apply, evaluate and create levels. We also welcome this because "Applying Technical Theory" and "Practical Engieering" (currently best approximated by the Apply and Create level scores) are two important factors in the eleven-factor model of core competencies in engineering (Male et al., 2011).

The fact that the project achieved significant progress even at higher levels of knowledge can probably be explained by several parallel, mutually reinforcing effects, in addition to those mentioned above, based on the literature: (1) The utilisation of Problem-Based Learning (PBL) and (2) robotics within a STEM context are two key elements of the programme. (3) The collaborative learning strategy, which was introduced in the third year, can be also a significant component.

A meta-analysis (Zhang & Ma, 2023) also showed that PBL promotes the development of higher-order thinking. The meta-analysis also highlights that the positive impact of PBL is strongest in terms of curriculum in engineering and technology, and in terms of age range among high school students, which in our case suggests a stronger impact, but also that the longer the project lasts, the greater the impact (strongest for projects lasting 9-18 weeks), which in our case may have limited the impact of PBL in promoting higher levels of knowledge.

Previous research has shown that if students are given tasks at higher levels of Bloom's taxonomy during their learning, they will perform well at higher levels later (Charoenphol & Bandyopadhyay, 2024; Vargas-Rodriguez et al., 2021). In our case, using Arduino enabled students to solve many higher-level tasks, which may also have increased the effect, as confirmed by Hsu & Tsai (2022), that obtained using robotics for STEM activities helps students learn how to apply what they have learned.

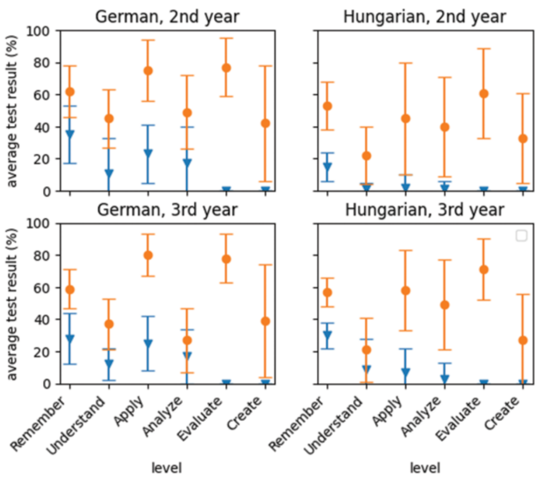
The third effect (which could only occur in the third year) was to make the tasks collaborative, as (Hidayat & Saad, 2025) demonstrated that in STEM subjects, peer tutoring had a positive effect on academic performance and other learning outcomes (such as critical thinking, which is essential for performing higher-level tasks).

To examine whether the methodological advancements implemented between the two projects resulted in a substantial alteration in students' progression throughout the duration of the project. The answer to this question was given by the year × pre/post interaction, which did not indicate a significant difference, and the effect size was also small ($F(1, 110) = 0.602$ $p = 0.440$ $\eta_p^2 = 0.005$).

It is evident from the findings that there is no significant impact of methodological advancements on the extent of students' knowledge development. This phenomenon can be explained by the observation that methodological advancements were predominantly advantageous for the group demonstrating weaker performance, while concomitantly leading to diminished progress among those exhibiting superior performance. The subsequent discussion will provide a more thorough examination of the effects of employing collaborative techniques.

Figure 4

Students' results at each level and their standard deviations. a) German students' results in the 2nd year, b) Hungarian students' results in the 2nd year, c) German students' results in the 3rd year, d) Hungarian students' results in the 3rd year. The triangles indicate the pre-test results, the circles the post-test results



The drop at the level of 'Analyze level' is interesting (see **Figure 4**) and has been examined in detail. The reason for the drop could be a specific question on the operation of transistors, which we do not seem to have been able to teach the students in a meaningful way in such a short time. However it is encouraging, that we found significant increases in almost all knowledge levels for all the groups (**Table 3**).

An interesting result is that in the 3rd year, there was no significant improvement in the two lowest levels of knowledge for Hungarian students, which may be due to the fact that the pre-tests were taken after the preparatory course.

Post-test comparsion

A significant difference was found between the post-tests of Hungarian and German participants in the 2nd year ($p_{tukey} = 0.012$); however in the 3rd year this difference was no longer detectable ($p_{tukey} = 0.876$).

We interpret this as meaning that German and Hungarian students worked more smoothly together in the 3rd year, and thus the previously significant difference between the nationalities post-test results disappeared.

Considering that as a suggestive evidence (due to the small sample size) we recommend, in order to promote a balanced approach to work, collaborative methods should be used to ensure that students have to work together. A good way to ensure collaborative learning in the project, is to have students from both sides listen to separate introductory lectures and then structure their worksheets so that students have to explain eachother what they have heard.

It is further possible that the preparatory course may have played a role in the disappearance of the significant difference between the post-test results. This is evidenced by the experiences of the pilot and the second year, in which it was reported that Hungarian students (according to their own admission) became demotivated by the fact that their German partners found the tasks easier. Consequently, over time, in most pairs, the German partner was assumed to complete the majority of the work.

According to this results, it can be beneficial to carry out a prior knowledge assessment and preferably pair members with similar levels of knowledge. If there is a significant difference between schools in this respect, it may be worthwhile to hold a preparatory session for the group with less experience before the project, so that weaker pupils do not give up and leave the work to their partners.

This statement is supported by our quantitative and qualitative results. Moreover, extant research demonstrates that student performance is independent of whether heterogeneous or homogeneous groups are formed (Wyman & Watson, 2020). However it should be noted that several studies examining collaborative learning focus on heterogeneous pairing because it yields significantly better learning outcomes in these cases (An & Zhang, 2024; Kanika et al., 2023). However, from the perspective of language learning (which constitutes an essential component of an exchange program), homogeneous pairing may be advantageous (Ghanbari & Abdolrezapour, 2020).

The objective of this study is not to determine the relative merits of homogeneous versus heterogeneous grouping; this is a separate question. Rather, the focus is on the implications of knowledge level disparity among students in a collaborative setting. Empirical evidence from our project indicates that when the discrepancy in the students' knowledge levels is substantial, collaboration tends to diminish, and in such instances, students may not derive the intended benefits. This mechanism has been demonstrated in previous research (Syarifudin et al., 2025).

This finding is supported by the disappearance of a significant difference in the third year between the post-test scores of the German and Hungarian students. Although the significant difference between the pre-tests of German and Hungarian students in the pilot project disappeared by the 2nd year, and therefore our present measurement cannot directly show whether the preparatory course in the 3rd year was the reason why we did not find a significant difference between the pre-tests that year, we believe that the disappearance of the difference between the post-tests of German and Hungarian students in the 3rd year's measurement is also effected by the preparatory course, that made Hungarian students more confident in participating in the collaborative work.

Testing satisfaction and attitude change

The average scores for the quantifiable questions by nationality are shown in **Table 4** in Appendix. According to the students, the project can be considered a success according to the questionnaire, with an average response rate above five for most questions. A significant difference between the German and Hungarian groups was found only for the first two questions, indicating that Hungarian students found the coordinators more straightforward, easier to understand, and more enthusiastic.

Overall, the results of our satisfaction and attitudes questionnaire suggest that the project definitely succeeded in being enjoyable for students and they felt that they had learned something useful. Timing and worksheet design require further optimization, based on student feedback.

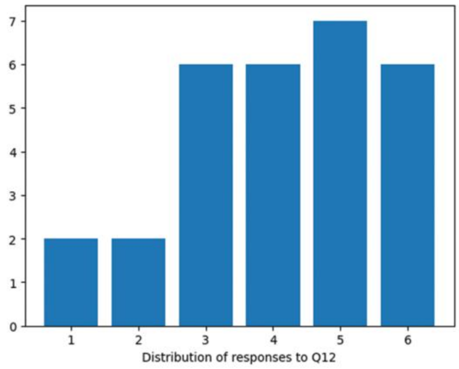
To answer H2, in addition to calculating means and standard deviations, we examined the distribution of responses, which shows that more students marked 'rather yes' (responses 1, 2, 3) than 'rather no' (responses: 4, 5, 6) for Q12 (**Figure 5**).

Interestingly, German students seem to have been more critical of our program, despite the results showing that we had a greater impact on changing attitudes in the areas of electrical engineering, science and computer science. It is worth highlighting that we found a significant difference in the questions on the coordinators. This is understandable, as it can be difficult for students to think of a completely unfamiliar teacher, whose mother tongue is different, as "direct". In addition, because German is not the mother tongue of the coordinators, they may have had more comprehension problems than their Hungarian counterparts.

Based on this fact, we believe that it is important that teachers from both sides should be actively involved in the delivery of the professional program to ensure that students from both nations feel that the project is equally accessible and understandable. This will also help to avoid language difficulties.

Figure 5

Distribution of responses to Q12: "I am more interested in electrical engineering, science and computer science because of the project than before"



Limitations

Although our results provide important foundation for future research, the study has limitations, that may affect the generalisability of its findings. The most significant constraint on the generalisability of the research findings is the relatively modest sample size (N = 30 participants/year). Consequently, the findings of this study cannot be regarded as definitive conclusions on the efficacy of the project. Consequently, the findings will function as suggestive evidence to support the further development of the project and the subsequent execution of further research.

Based on the experiences and measurement results of the two years preceding the projects presented in this article, we attempted to pair students with similar knowledge levels. To do this, we sent the pre-test to the German school in advance and had our own students complete it before the project. A difficulty was that, despite our request (which we could not make compulsory), many of the German students did not give their names, so we could only take the results of the pre-tests into account in broad terms when pairing them. It was also difficult for the results of the best performing Hungarian students to be also generally lower than those of the German students.

In the context of knowledge tests, the Cronbach's alpha value of the pre-test was found to be low, likely attributable to the students' initial low level of subject knowledge. This resulted in a low variance of the pre-tests, potentially due to random answers that reduced the alpha value. Consequently, the low Cronbach's alpha value of the pre-test does not necessarily imply that the test possesses low reliability, if the knowledge test is not a homogeneous construct that measures multiple concepts (which is the case here, as we measured both the students' physical concepts and their coding knowledge) (Zitzmann & Orona, 2025); however, it does necessitate caution when generalizing the results.

In the context of knowledge tests, a potential factor contributing to the reduction in validity may be the absence of a quantitative validity assessment. Despite meticulous development of the test, drawing upon the insights from the pilot year and feedback from in-house experts, a quantitative validity test was not conducted.

The satisfaction and attitude questionnaire for this project focused less on measuring attitude change than on measuring student satisfaction. A multi-faceted assessment of satisfaction is required to improve the project.

Thus, the satisfaction and attitude measurements did not include a pre-test, and attitude change was measured using a single question. This could bias our results on attitude change, as it is possible that students may have marked a higher value for compliance than they actually thought.

The lack of control group in the study design in the second and third year, makes it difficoult to attribute the results solely to the project and its methodological improvements.

Future work

The present study has provided a foundation for the development of a PBL-based, Arduino-using STEM student exchange program framework, with the objective of enhancing students' knowledge and motivation, and reducing the gender gap in STEM fields. A review of the extant literature indicates that it may be advantageous to augment this framework with the application of AI, as it has been demonstrated to be conducive to the development of students' knowledge and motivation. The integration of AI into the framework has the potential to yield a range of benefits, including enhanced efficiency in data collection regarding students' prior knowledge and abilities, the identification of patterns in the collected data, the characterisation of student groups, and the subsequent fine-tuning of the curriculum and methods employed. Additionally, it facilitates the provision of personalised, real-time feedback to students during the project (Abisoye, 2024). During the project series, we found that a one-size-fits-all approach can be detrimental due to the greater differences in students' initial knowledge and abilities. This problem can be mitigated by moving towards precision education, in which rapidly developing AI can provide important support for individual learning paths (Nagaraj et al., 2023; Zawacki-Richter et al., 2019).

Integrating AI into the project may also be beneficial, as AI-supported problem-oriented project-based learning (PBL) has been found to be significantly more effective than traditional PBL in developing critical thinking skills in biology education (Habibah et al., 2025). Another study shows that AI-supported PBL increases collaboration and creativity among high school students (Amiruddin et al., 2025).

In future iterations, we plan to integrate IoT-based components into our STEM curriculum, because recent evidence shows that IoT-enhanced learning environments significantly improve student engagement, motivation, and learning outcomes. A recent systematic review of empirical studies found that IoT-supported activities consistently foster knowledge building, autonomous learning, and positive changes in students' attitudes and motivation (Tsipianitis et al., 2025). Incorporating IoT thus offers not only deeper conceptual understanding, but also cultivates key 21st-century competencies such as data-driven thinking, problem-solving, and collaborative project work, making it a promising direction for enhancing both cognitive and affective learning outcomes (Ariza & Baez, 2021; Sopapradit, 2022).

The implementation of a "STEM-AI-IoT-based cross cultural project learning" framework would have the potential to facilitate the more effective development of students' knowledge and motivation in STEM fields, as well as the more efficient promotion of gender equality. Based on the research presented in this article, it may be beneficial to develop a STEM-AI-IoT-based cross-cultural project learning model.

CONCLUSION

In this study, we have shown the development of a STEM student exchange program and its results in terms of student knowledge and satisfaction/motivation. The program was successful in engaging students' knowledge and attitude in physics and engineering and provided methodological considerations for future similar programs.

H1. The project can achieve a significant increase in students' knowledge, irrespective of their nationality.

Our results suggest that the project achieved significant growth among students from both participating countries in both years presented. H1 was supported by the pre-post main effect's significancy, and that the post-hoc tests showed that there was a significant difference between the pre- and post-test scores for both nations in both years.

H2. The project motivates students from both countries towards STEM fields

The distribution of responses to question 12 of the satisfaction and attitudes test showed that more students were motivated towards science careers (19 of 29 respondents selected an option closer to "yes"). This is good feedback on the effectiveness of the project, but it is not yet sufficient to prove or disprove hypothesis H2 therefore further studies are needed. However this finding is consistent with previous studies. A meta analysis, shows that PBL has positive effects not only on academic performance, but on self-emotional attitudes and values and thinking skills too (Zhang & Ma, 2023)

H3. The project developed students' knowledge at all levels of Bloom's taxonomy.

The statistical analysis also showed that for both years, we were able to achieve significant increases in students' knowledge for most levels of knowledge in both nations (H3).

This result makes the use of exchange programs promising for knowledge enhancement and is consistent with the literature, according to which several components of our framework reinforce learning at higher levels of knowledge.

H4. The methodological improvements (making the project collaborative) that we introduced between the two projects caused a significant change in students' progress.

The fact that the significant difference in the post-test disappeared by the third year (there was no significant difference between the pre-tests in either year) may indicate that the preparatory course and collaborative work (methodological improvements between the two years) have been really useful, so H4 appears to be correct. Previous research also supports the idea that combining collaborative learning with PBL is more effective than PBL (Sugianto, 2022).

The findings suggest that the student exchange program can successfully enhance the participants' knowledge and interest in STEM fields. The methodological developments are promising in terms of increasing the efficiency of the project.

Acknowledgement

This work is supported by the Research Program for Public Education Development of the Hungarian Academy of Sciences (Project Number: SZKF-7/2022). This work is supported by the Digital Education Development Competence Center at Eötvös Loránd University, Budapest, with project number 2022–1.1.1-KK-2022–00003. We would like to thank our colleagues A. Tuppack and T. Stein for their work in organising the exchange project.

Funding

This work is supported by the Research Program for Public Education Development of the Hungarian Academy of Sciences (Project Number: SZKF-7/2022). This work is supported by the Digital Education Development Competence Center at Eötvös Loránd University, Budapest, with project number 2022–1.1.1-KK-2022–00003.

Ethical statement

The authors state that the research was conducted in accordance with the principles embodied in the Declaration of Helsinki and in accordance with local statutory requirements. All participants in the exchange and related research were volunteers with parental consent. All participants were fully informed that anonymity is assured. No personal data was collected and processed during the research. One exception to this was the collection of students' names for pairing in the third year, which was done voluntarily by the students.

Competing interests

The authors declare that they have no competing interests.

Author contributions

Sándor Gergely Pesthy contributed to the conceptualization, data curation, formal analysis, investigation, methodology, project administration, provision of project materials, supervision, original draft writing, review and editing of the manuscript, and visualization. Mihály Hömöstrei contributed to the conceptualization, methodology, investigation, supervision, and review and editing of the manuscript. Péter Jenei contributed to supervision and review and editing of the manuscript. All authors read and approved the final manuscript.

Data availability

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

AI disclosure

This manuscript was prepared with the assistance of ChatGPT, a language model developed by OpenAI, which was used only for refining language. The authors have reviewed, revised and approved the final content.

Biographical sketch

Sándor Gergely Pesthy graduated as a physics and chemistry teacher, then began his doctoral studies in physics education in 2022. He is currently a doctoral student at the Institute of Physics and Astronomy, Eötvös Loránd University (ELTE). His area of expertise is physics didactics, specifically the use of microcontrollers and rocket science in physics education.

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APPENDIX: THE PRE AND POST KNOWLEDGE TEST

Table 4

The mean and standard deviation of the responses of Hungarian and German students in the questionnaire. For all questions, students were asked to rate on a scale of 1 to 6, with 1 being the worst and 6 the best. The last column shows whether the difference between the two groups is significant. To illustrate this, the p-value given by the Mann-Whitney test is shown

Question	Hungarian	German	p
Q1. The coordinators were straightforward.	5.67 (SD=0.62)	4.71 (SD=0.73)	< 0.01
Q2. The coordinators were enthusiastic and easy to understand.	5.53 (SD=0.64)	4.79 (SD=0.80)	0.011
Q3. The timing of the Arduino part of the programme was appropriate.	4.93 (SD=0.88)	5.14 (SD=0.66)	0.583
Q4. The curriculum was interesting and included new knowledge.	5.66 (SD=0.62)	5.14 (SD=0.86)	0.079
Q5. The theoretical lessons can be applied to the project and to solving the tasks.	5.13 (SD=0.83)	4.86 (SD=0.86)	0.392
Q6. How would you evaluate your opportunities and experiences?	5.13 (SD=0.74)	5.29 (SD=0.83)	0.473
Q7. The activities carried out during the project met or exceeded my expectations for the project.	5.53 (SD=0.64)	5.00 (SD=0.78)	0.062
Q8. The worksheets provided enough information to carry out the experiments.	4.73 (SD=1.10)	4.07 (SD=0.92)	0.088
Q9. The experiments carried out during the programme were interesting and challenging for me.	5.00 (SD=0.93)	4.57 (SD=0.85)	0.280
Q10. The timing of the sessions struck a good balance between structured time (new information transfer) and time for projects.	5.26 (SD=0.70)	5.00 (SD=0.96)	0.513
Q11. The theoretical tutorials developed my understanding of electronics and programming.	5.20 (SD=0.86)	5.14 (SD=0.95)	0.944
Q12. I am more interested in electrical engineering, science and computer science because of the project than before.	4.06 (SD=1.62)	4.14 (SD=1.41)	0.911
Q13. I would be happy to recommend the programme to others.	5.53 (SD=0.64)	5.50 (SD=0.65)	0.900

Table 5

The table presents the questions of the knowledge assessment and specifies whether each item was administered in the pre-test, the post-test, or in both phases of the measurement

Question	Test	Type
What do the following prefixes mean?	pre	multiple choice

Enter the result of the following operation (fractional addition).	pre	short answer
Convert the following units of measurement.	pre	short answer
What is the speed in m/s of a body that reaches a wall 8 m away from it in 5 s and returns to its starting point?	pre	short answer
What kind of device connection diagram can be seen in the picture? (H-Bridge)	pre-post	short answer
Match the corresponding commands with their descriptions.	pre-post	pairing
In which diagram can you see a circuit in which you can control an LED using program code?	pre-post	multiple choice
What do you see in the picture? Answer with one word. (Transistor)	pre-post	short answer
What happens when the following code runs?	pre-post	long answer
Write down the command that would pause the program for 2 seconds.	pre-post	short answer
List the circuit elements you know.	pre-post	long answer
How many times does the pinMode(8, OUTPUT); command run in the code below?	pre-post	short answer
Describe the basics of transistor operation.	pre-post	long answer
Write a code that turns on digital port 4 if the variable named "x" is greater than one.	pre-post	long answer
Present the parts of the Arduino program code and their main features.	pre-post	long answer
The time measured by the ultrasonic distance meter was 6 s, and the speed of sound was 340 m/s. Could the distance between the car and the wall be 340*6 m? Why?	pre-post	long answer
What is the difference between the possible operations of an H-bridge and a transistor-driven car model?	pre-post	long answer
Organize the Arduino commands you know according to whether they are part of void setup () or void loop ().	pre-post	long answer

List of abbreviations

AI – Artificial Intelligence
H-bridge - an electronic circuit allowing the engine to rotate in both directions
IoT – Internet of Things
LED - light emitting diode
PBL – project-based learning
STEM - science, technology, engineering, and mathematics