PICA-PICA: Exploring a Customisable Smart STEAM Educational Approach via a Smooth Combination of Programming, Engineering and Art

Takashi Nagai
Institute of Technologists
Gyōda, Saitama
Japan
0000-0002-6395-2258

Strahinja Klem
Durham University
Durham,County Durham
United Kingdom
0000-0002-6965-4868

Mizue Kayama
Shinshu University
Nagano, Nagano
Japan
0000-0001-9654-7112

Takehiko Asuke
School Board of Ina City
Ina, Nagano
Japan

Maram Meccawy
King Abdulaziz University
Jeddah
Saudi Arabia
0000-0003-2526-5075

Jingyun Wang
Durham University
Durham, County Durham
United Kingdom
0000-0001-9325-1789

Alexandra I. Cristea
Durham University
Durham, County Durham
United Kingdom
0000-0002-1454-8822

Craig D. Stewart
Durham University
Durham, County Durham
United Kingdom
0000-0001-7548-1660

Lei Shi
Newcastle University
Newcastle-upon-Tyne
United Kingdom
0000-0001-7119-3207

***Abstract*—The STEAM approach in education has been gaining increasing popularity over the last decade. This is due to its potential in enhancing students' learning, when teaching arts and scientific disciplines together. This paper introduces the PICA-PICA concept, where we aim to develop a smart customisable environment, combining, in a unique way, *teaching programming in conjunction with the engineering of artworks*. The PICA-PICA concept was implemented, used and tested in real-life, by upper primary school students in Japan, during a 4-day workshop. Initial results illustrated the quality of the solution proposed by PICA-PICA. We noted that the integration was perceived as *smooth*, and not contrived: all participants understood how to use the PICA-PICA environment to engineer programmable art objects. Furthermore, the PICA-PICA approach led to *high motivation*: children did not get bored and were fully engaged. Finally, the *quality of their work* as a learning outcome was high: by including a programming segment with the other expressive activities in the artwork, the children were able to design the electronics in a more concentrated and meaningful way than their curriculum-structured learning. This study also presents an innovative implementation of the STEAM approach using Micro:bits technology to create exciting artwork whilst using household recyclable items, which also teaches about sustainability. The involvement of parents and their interest in learning is another unique aspect of this study.**

Index Terms*—STEAM education, programming learning, artwork, micro:bit, primary education.

I. Introduction

STEAM [17] is an emerging educational approach, which involves integrating the teaching of Science, Technology, Engineering, the Arts and Mathematics, in order to motivate students and encourage them to become curious learners. It is expected to allow them to use critical thinking skills to come up with creative solutions to real-world problems. Whilst STEM (Science, Technology, Engineering and Mathematics) is focused on learning the so-called 'hard' skills, STEAM adds the 'soft' skills to the mix, in order to leverage students' overall skill set and prepare them for future studies (higher education), career challenges and life in general. It is believed that STEAM will produce students with better problem-solving skills, as many researchers [6], [14], [18], [22] have reported positive results after they had integrated teaching technologies with arts by following the STEAM approach. Recently new technology, such as AR, VR, AI, robotics, etc, has been incorporated into STEAM to enhance Computational Thinking education, which turns further learning into more a interactive environment. However, previous STEAM research lack of providing substantial methodological changes in the classroom [9], and little research provides STEAM methodologies and teaching resources [11]–[13]. Marín-Marín et al. [19] highlighted that further direction not only should support the reflection among teachers [2], but also encourage the reflection of students using a creative and collaborative approach [8].

The Minami-Minowa Village Community Centre in Japan held a programming workshop for primary school students on September 2019, with the intent to make it a fun and interactive introduction to programming. Furthermore, the village also holds an annual illumination festival in October at the nearby Oshiba Plateau[1]. To combine these two events, in 2019, the authors organised the PICA-PICA study (where 'PICA-PICA' means to sparkle or shine in Japanese). Thus, the overarching research question targeted by the PICA-PICA study was:

Can the combination of learning art, engineering and science, at the same time be beneficial for students?

As sub-questions, we particularly explored:

[1] Shinshu Oshiba Plateau: https://kankou-minamiminowa. nagano.jp/oshiba-plateau/

Can primary students successfully learn programming and artistic creation of illuminated objects at the same time?

Would students perceive such a combination of programming, hardware handling, artistic creation, and light manipulation as cognitive overhead?

Would carers (parents) perceive such a STEAM-based pedagogy as beneficial for their children?

The main contributions of this work are thus:

- a smart method of combining engineering, programming and art towards teaching primary school children these complex concepts together;
- creating a dedicated smart STEAM learning system, as well as dedicated learning material;
- evaluating this smart STEAM learning system in real-life environments, gathering first-hand feedback from the experience of both children (students) and their carers (parents);
- evaluation showed that the PICA-PICA approach was perceived as a smooth, integrated solution, in spite of its complexity, and that it increased motivation in students, and produced high-quality learning.

II. Related Work

STEAM has emerged as a popular pedagogical approach, educators agree that STEAM enhances students' creativity and thinking skills [21]. According to a recent study [21], conducted to examine the effects of traditional methods, both STEM and STEAM-based activities were targeted at primary school students' environmental awareness. STEM applications were shown to be more effective than traditional applications, whilst STEAM applications were found to be more effective than either STEM or traditional approaches. The STEAM approach in teaching and learning has many advantages, as it creates a stronger engagement of students and teachers in learning activities. This approach also establishes a real-life connection with STEM subjects, through the use of arts and design [3]. The STEAM learning activities help in developing an innovative mindset; this interdisciplinary approach contributes to the development of the learners' problem-solving skills and creating 'out of the box' solutions [3]. Moreover, STEAM nurtures collaborative work, as its lessons are collaborative by nature [3]. This collaboration is not only amongst students but more importantly, between teachers of subjects that traditionally would have been considered unrelated. This collaboration helps teachers develop lessons together, instead of in isolation [14]. Students sharing ideas and experiences in STEAM classes have been shown to lead to enhanced lesson outcomes and shared knowledge [4], [5].

Thus, STEAM-based learning is highly regarded. However, true integration, resulting in 'smooth' STEAM, is still an area of active research [1], [16]. Presenting a practical realization of the STEAM approach which delivers on the promise of integrating teaching arts and science within a collaborative learning environment to produce interesting artwork is the focus of this paper.

When it was launched in 2016, many researchers and educational institutes around the world found the BBC's mico:bit a useful tool for teaching computer science and programming, wherein technology is an integral part of STEM education. One study [25], which involved 36 students from four countries, was conducted to teach programming skills. The results showed a clear relationship between the quality of the experience obtained by using the Micro:bit tool for learning and its educational value. Moreover, it showed that female students in particular liked coding more after using this tool; the study attributed this finding to the opportunities provided to them during the class. Another study [23] described how it used Micro:bits to teach programming in primary and secondary schools. The authors reported positive outcomes in terms of developing students' programming skills and algorithmic thinking, as well as keeping them engaged in the learning process. A third study [10] has also reported positive results when teaching programming to primary school children using new materials, such as the Micro:bit, which keeps students engaged and interested. Many other studies have reported similar positive outcomes in using Micro:bits for teaching programming in schools [7], [15], [20].

One of the design goals of enhancing usage of Micro:bits by the BBC and its partners was for it to be applicable beyond teaching computer science: "The micro:bit project aimed to stimulate curiosity about how computing can be applied across a variety of disciplines, ranging from science and technology/engineering to the arts and mathematics (STEAM)." [7]. However, the majority of studies reported in the literature focus on the use of Micro:bits in STEM education; it has been used to teach programming, algorithms, engineering and computer science-related topics. Very few studies, if any, reported its use in relation to teaching arts or any non-technical subjects. One study [24] reported the use of Micro:bits in primary education where one class investigated how Victorian inventions use light to solve problems, they created prototypes using Micro:bit, LED and conductive dough. The students deconstructed their models, and re-represented them as a physical dance performance so that others could guess their inventions. This experiment connected the art (dance) with physical modelling (using dough) and digital technology (Micro:bit & LED). It involved a lot of collaboration and teamwork between children, which created a shared understanding of the subjects and provided the audience with an appreciable artistic output.

The work presented in this paper describes a novel experiment in STEAM education that involves some similar items to the work presented in [24], such as LEDs and the use of Micro:bit, but also recyclable household items, to create exciting illuminated artwork and models. Thus, unlike the experiment in [24], where the artistic side was a separate part of the project, in PICA-PICA, we seamlessly integrate programming, engineering and art, so that students are able to create an artistic object, whilst programming its light messages or designs.

III. PICA-PICA Study: Design and Methodology

We first overview the PICA-PICA study design, in terms of the components of the smart, customisable environment, such as hardware, software, and materials for the artwork. Then we detail the experimental study design, consisting of a real-life workshop, and the data gathering procedures.

A. PICA-PICA Hardware

The hardware had to obey several constraints. It had to be relatively cheap so that several copies can be made available to children at the same time. It had to be portable, due to the fact that it had to be transported to the place where the workshop took place. It also had to be small, light and durable, as it had to be handled by primary school children.

As such, the hardware consists of 7 parts: (a) Microsoft micro:bit[2]; this was used at it conforms to the above restrictions, and is also programmable to a wide range of desirable standards and complexities, (b) LED string; this was used to create the illumination, (c) LED connection panel; this was used to connect the LED to the micro:bit (d) LED control board; which powered the LEDs via the micro:bit, (e) base; to hold the setup, (f) connection cable; to link the LEDs to the board and (g) battery box to power the micro:bit (see Figure.1). The micro:bit uses 5 ports (3 digital pins, power and ground). The digital pins are used for general output and are the main interface to other hardware when programming. The multitude of them allows for up to 3 parallel external processes to run at once, in our case 3 separate lights. The LED string is 2m long and has 20 LEDs on it. We used this length of string, to allow students to create many types of art displays, which would let their imaginations roam freely. The LED connection panel can be connected to three LED strings. The parts of this board are shown below: 1) PICA-PICA board 1 piece, 2) 2 kinds of resistors, 3 resistors each, 6 resistors in total, 3) 1 terminal regulator, 4) 3 MOS-FETs, 5) 2 capacitors (1 each), 6) 2 types of XH connectors (5 pcs), and 7) 1 terminal block.

The LED control electronics board uses MOS-FETs to switch the LED strings and supply power to the micro:bit. The terminal block and connectors are used to facilitate this process, whilst the resistors, capacitors and terminal regulator all serve to maintain the correct voltage and current.

To create the smart STEAM learning environment, we soldered these to the PICA-PICA board, to form an electrical circuit, consisting of the LED string lighting control unit and the power supply unit for the micro:bit. On the base, the PICA-PICA board, micro:bit (front) and LED connection panel (back) are fixed. The connection cable is used to wire the PICA-PICA board to the micro:bit and the speaker terminal.

B. PICA-PICA Software

To continue the build of our PICA-PICA smart STEAM learning system, the choice of software is crucial. The software requirements are, on the one hand, compatibility with the hardware; and on the other hand, support for introductory level, block-based programming - due to the fact that our students were primary school students, and this was an exercise of introducing them to programming. Other desirable features were flexibility and extensibility for further potential projects.

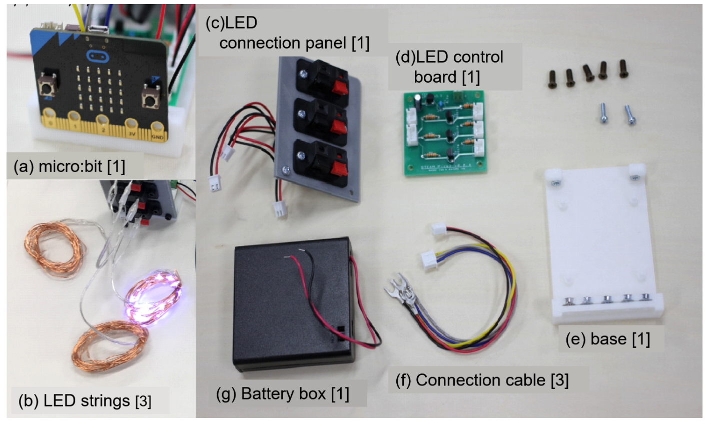

Fig. 1: Components of PICA-PICA materials.

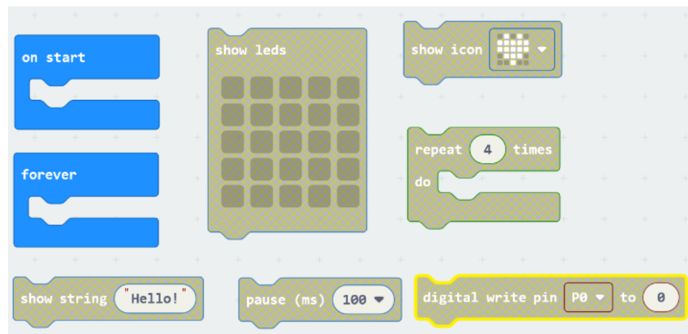

Fig. 2: MakeCode blocks that were used by students in their programming.

Thus, Microsoft MakeCode[3] is used to program the LED strings and built-in LED display (on the chip itself). The API is realised as a web page, which can be run online, or on a locally hosted NodeJS server. It comes with many features, including those to program with pre-made code blocks (or Python/JavaScript, should one so choose), capabilities to digitally simulate the full workings of a micro:bit, as well as a compiler into .HEX files, which is the input format for the chip.

Although many more functionalities are available, the participants in the study made use of only 8 types of blocks within the illumination program (on start, forever, repeat, pause, digital write, show string, show icon and show LEDs, as shown in Figure 2), primarily due to their relevance and simplicity. This allowed the students to decide which ones to light up, as well as at which point in time, making it able, with a few simple programming blocks, to create relatively complex and compelling illumination patterns.

[2]https://microbit.org/

[3]https://makecode.microbit.org/

C. PICA-PICA Artwork Material

The final part of the PICA-PICA smart STEAM learning system is represented by the artwork material. Here, the purpose was to allow freedom of the creative flow and multiple choices of expression.

Hence, several types of materials were made available to create the artwork: aluminium wire, wood scraps, cushioning material, masking tape, screws, nails, glue sticks, wood glue, and recycled materials brought by the participants.

D. Outline of the PICA-PICA Workshop

The workshop was held over a period of four days (2019.9.7 – 2019.9.10) as part of the "Programming Course: PICA-PICA Project" organised by the Minami-Minowa Village Community Centre. In total, ten pairs of children (i.e. 10 children with 10 guardians) from the 4th to 6th grade participated, along with their families. The mixture of children and their carers (parents) provided additional support for the children, as well as an opportunity to collect feedback from both children and parents. Finally, by bringing the parents on board with the new pedagogical approach proposed by the PICA-PICA smart STEAM learning system, the hope is to have a long-term impact on the children's education. Observations and feedback from parents, as shown in section IV-C further support this approach.

A summary of the four-day workshop is given below:

- **Day 1:** Introduction to the micro:bit and practice programming.
- **Day 2:** Use of Programs for illumination (1: sequential processing) and artwork (1)
- **Day 3:** Illumination Programming (2: iterative and increasingly complex process) and artwork refinement (2).
- **Day 4:** Finishing and exhibition of the work.

Pre-soldered and pre-assembled hardware was used here. The subject of the artwork was "Nature in Oshiba", to both connect the task to something familiar to the students, and enhance the connection to the local environment, as well as focus on an area of great interest in Japanese art, that of nature.

E. Data Recording at the PICA-PICA Workshop

We recorded all parts of the workshop experience. This included the programs created by the students, which we then could analyse in more detail, specifically in terms of length and complexity, and artwork was saved in the form of images. Additionally, we asked all participants to write a 'summary card', reflecting on their understanding, creativity, embodying ideas, expansion, and (based on this experience) application to their daily life. Finally, we recorded feedback and comments from the families and carers.

IV. Results of the PICA-PICA smart STEAM learning system in action

A. Data Analysis of the PICA-PICA Workshop

Programs created by the primary school students consisted of an average of 45.8 blocks ± 16.9. Hence, the outcome

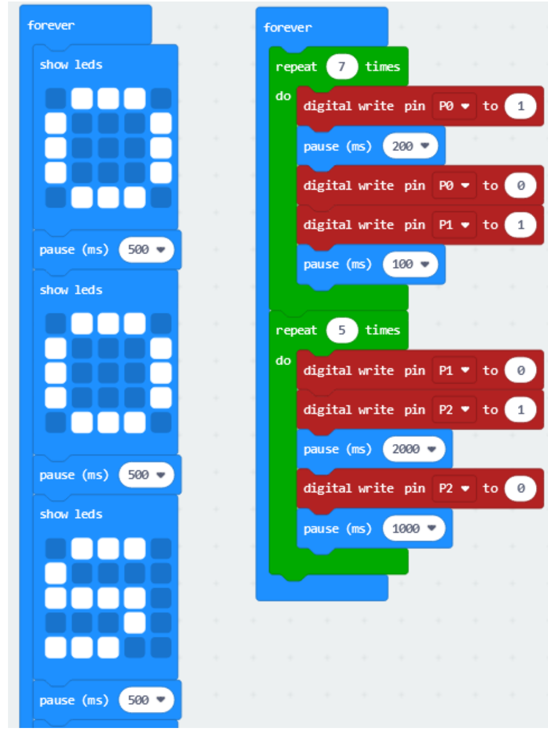

Fig. 3: An example program created by students in MakeCode

size varied significantly between participants. Each program consisted of a group of blocks that were executed in about 14 seconds and were placed in a "forever" block, so students could see their program repeating over the whole time of the exhibition. Figure 3 shows an example (excerpt) of a program created by one of the participants, which represents one of the shorter programs. We also analysed the complexity of the programs created, besides their length. Thus, 'Repeating' blocks (as e.g. the 'repeat' used in Figure [**?**]) were used by 9 participants, with an average of 1.7±1.5 locations. In addition to the flickering LED strings, all participants displayed text and icons on the micro:bit LED panel. Furthermore, all participants used multiple "forever" blocks to process the LED strings and the micro:bit LED panel in parallel.

B. Student-created Artwork and Programming

An example of an artwork created by the students is shown in Figure [**?**]. It was created by a 5th-year student. The main materials used were recycled materials - PET bottle caps, egg cartons, pine cones, and masking tape - showing great expressivity and creativity in the participant. 3 LED strings flickered at different times, and the LED display showed messages in a self-made font.

C. PICA-PICA Observations and Feedback

After the PICA-PICA workshop, we asked all participants to make a summary card, reflecting on their understanding, creativity, embodying ideas, expansion, and application for daily life. The full summary card consisted of ten questions. The first five of these were ordinal questions, where 1 meant

TABLE I: PICA-PICA first five questions to participants, with mean and standard deviation.

Questions	Mean	Std Dev
Did you understand how to program with micro:bits?	1.2	0.4
Were you able to create the illumination you wanted?	1.2	0.4
Do you think you were able to convey your message through your work?	1.5	0.5
Do you think it was good for you to participate in this course?	1.0	0.0
Did you understand the teacher's explanation in this class?	1.3	0.5

Fig. 4: Examples of participants' work. Upper:day time, lower:night time.

"strongly agree" and 5 meant "strongly disagree". These can be seen in Table 1 with their respective standard deviations and means, showing the notably positive responses given by the participants (all responses are close to 1, i.e. "strongly agree"). Thus, participants understood how to program with micro-bits, were able to create the illumination they wanted, were able to convey their (artistic) message through their work, and understood the teacher's explanations in the workshop. They clearly loved to participate in the PICA-PICA workshop, with all participants answering unequivocally with "strongly agree".

The next four were free-form questions, starting with "What did you learn for the first time?" which revealed that for all of the students, this was their first contact with programming and electronics. Similarly, "What did you think was difficult?" showed, interestingly, a mix between the artistic and technical side of the workshop, but leaned more heavily towards the latter. Another question was "What would you like to do at home based on what you have learned?", which showcased a lot of enthusiasm towards the new skills, and a desire to apply them. Finally, on the last question in this set, "What would you want to do with the micro:bit?", it is interesting as well as important that all of the responses involved some form of creative work, like creating video games, music or more intricate messages.

The last part of the feedback sought was also free-form, however, directed towards the parents and guardians: "What were your impressions of the lecture?". One of them commented that *"It was good that we were able to think about the order of programming by moving the actual objects instead of just thinking about it"*. A second parent wrote: *"I was worried about whether I would be able to make the illumination before participating. However, thanks to the support of the teachers and their preparations, I was able to enjoy immersing myself in creating the artwork with my children"*. A third added: *"I was amazed at how quickly the children absorbed the explanation. My child has been making some programs at home using Scratch and other tools, but he has never run an actual machine, so this was a good opportunity for him. On a PC, He can just build a piece of programming without thinking about it, but on an actual machine, it is necessary to think in order. I am glad that I could participate in this course"*. Another parent stated that: *"It was a valuable experience for me. It was good to participate in this event. It was fun for both parents and children to communicate and learn about programming"*. The fun element was agreed upon by two more parents: *"I think he learned how fun and difficult it is to realise what he has imagined"*. and *"We were able to experience the fun of programming our own illumination. I think we can enjoy the illumination in a different way than before"*.

Moreover, some parents had initial fears that were later resolved: *"It was difficult because I had never done anything like this before. However, when the illumination lit up as we had planned, my son and I rejoiced, "Yay! I was so happy. I learned that the illumination is created in this way"*. And: *"When I heard the word "program," I had a difficult image. However, the content of this course was easy for children to use and understand, and I also enjoyed it. I am looking forward to going to the exhibition hall to see the good works we made"*. Hence, the parents' and guardians' feedback showed that whilst the content and method of the PICA-PICA approach was new to both parents and their children, they learned to embrace it and see the potential benefits. Parents appreciated the learning outcomes for their children.

Additionally, we monitored specifically children in the upper grades of primary schools. They demonstrated that they did not get bored and were fully engaged in the workshop during the two-hour sessions.

Summarising, the results from both parents and children of different ages are very positive. We believe thus that, by including a programming segment and engineering work with the other expressive activities in the artwork, the children were able to design the electronics in a more concentrated and meaningful way.

V. Conclusion

Using the proposed PICA-PICA smart STEAM learning environment in this paper, we conducted a four-day workshop with micro:bit programming and artistic creation for upper primary school students and their parents in Japan, totalling eight hours in duration. Children in the PICA-PICA project were able to produce creative artwork and then illuminate it through programming the micro:bit kit. Both children and their families who have participated in this project showed great appreciation, creativity and enthusiasm. By including a programming segment with the other expressive activities in the artwork, the children were able to design the electronics in a more focused and meaningful way.

Thus, we have shown in this paper a smart, smooth new method, PICA-PICA, of combining engineering, programming and arts, towards teaching primary school children about all of these relatively complex concepts in a smooth way, which, from preliminary results, seems to not provoke additional cognitive overhead, and has been very well received by both students and carers. Additionally, we have implemented the PICA-PICA system and evaluated it, creating concrete ways for further implementation and research in the area.

This further demonstrates the value of teaching arts with science and science with arts, as advocated by the STEAM approach. However, the restrictions to face-to-face contact that resulted from almost two years of living with the Covid-19 global pandemic drove us to think in the direction of a more sustainable and practical way to practice STEAM learning, one that would not be affected by such closures or geographical distance. At present, the newly emerging VR/XR technologies seem to have the potential for this task, and thus would most likely be the next step for our research moving forward.

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