Design-Based Learning and Constructionist Learning Principles to Promote Artificial Intelligence Literacy and Awareness in K-12, a Pilot Study

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The IAFOR International Conference on Education in Hawaii 2023
Official Conference Proceedings

Abstract
There is a strong interest in engaging young learners in understanding and using Artificial Intelligence (AI) by providing opportunities to develop skills and competencies both from a technical and ethical perspective. However, how we should teach AI is still to be discussed in-depth. There are relatively few studies that investigate the methodology of learning programmes for K-12 students. The literature has highlighted how Design-Based Learning (DBL) could successfully lead learners to develop their knowledge of AI by engaging in an iterative, creative, and collaborative process underpinned by a constructionist pedagogy that fosters understanding and building connections with the 'real-world'. In this paper, we describe the implementation of a learning programme on AI, based on DBL and constructionism, co-designed with primary school teachers, and piloted with a group of students (10-12 years of age) in Ireland. Students engaged in a series of hands-on activities and then experienced the whole design process of AI working in groups. They conducted some research on health and well-being to identify potential issues they could tackle using AI. Then, they ideated and created a prototype of their solution using Scratch and Machine Learning for Kids. In this paper, we discuss reflections from the teacher and insights on participants' learning experiences. The study illustrates how through DBL it was possible to give students the agency, as creators, to shape technologies for good, and how a programme based on DBL and constructionist learning principles created a felicitous environment to learn and reflect on AI while developing 21st-century skills.

Keywords: Artificial Intelligence, K-12, Design

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Introduction

The use of Artificial Intelligence (AI) and data analytics in education as instruments to enhance teaching and learning are now receiving a lot of attention (Chassignol et al., 2018). However, AI like other emerging technologies is changing our world, challenging us to rethink not only education but also our lives as 21st-century citizens (OECD, 2021). DigComp 2.2 EU framework on digital competencies for citizens outlines the relevance of AI in terms of knowledge (i.e. recognising AI systems and their uses), skills (i.e. enabling a day-to-day interaction with the technology), and attitude (being aware of both negative and positive impact of AI) (Vuorikari, Kluzer, & Punie, 2022). However, only a few studies examine how to teach AI in schools (Kahn and Winters, 2021). In today's world, children should be prepared to take an active role in designing and using AI-enabled technology (UNICEF, 2020). Therefore, we need to provide opportunities for them to develop skills and competencies to be the ethical innovators of the future (NCCA, 2020). Even though AI learning programmes for young students, resources, and activities are available online, there are very few studies that try to share best practices and guidelines to design them (Zhou, Van Brummelen, & Lin, 2020). In this paper, we describe how we aim to engage students through co-designing with teachers a learning programme on AI integrated with curricular subjects. This trial was led by one teacher in Ireland with students from 10 to 12 years of age as part of an extensive study on Education and Public Engagement. We would like therefore to share our methodology, design process, and lessons learnt from the experience in class.

Background

Research suggests that since experts' knowledge is built around core concepts and big ideas, then the curriculum should be organised in the same way (Bransford, Brown, & Cocking, 2000). AI big ideas are framed for K-12 students around five main concepts (Touretzky et al., 2019), Perception, Representation and Reasoning, Learning, Natural interaction, and Societal impact. In other words, how a robot (also called "agent") uses sensors to gather information on the environment, how AI systems analyse data, find patterns and make predictions, how this software relates to humans, and what is the impact of this technology on our lives. Definitions of AI are still evolving though researchers refer to AI literacy as a set of competencies that everyone needs to be able to navigate and question a world (work, school, health...) more and more influenced by emerging technologies (Long & Magerko, 2020). There is a strong interest in engaging young learners in AI providing them opportunities to develop skills and competencies both from a technical and ethical perspective. However, how we should teach AI needs to be discussed in greater depth (Marques, Wangenheim, & Hauck, 2020).

The importance of a constructionist pedagogy in AI is evidenced by research (Kahn & Winters, 2021). Constructionism states that learning can be particularly beneficial if it happens through building and creating artifacts or models that can be shared. Those models or "objects to think with" (Papert, 1980) can be physical or digital, and learners are considered active creators of their knowledge (Papert, 1980). Furthermore, learning situations and activities should be designed and developed connected to/with a meaningful context for the learner i.e. possible real-world problems students can resonate with (Butler, 2007). Engaging children to design AI models that could potentially help others, pedagogically represents a valuable opportunity to deepen their understanding. A Design-Based Learning (DBL) approach, thanks to its iterative and creative process (from research to ideation, from prototype to test and share), facilitates children's AI understanding while at the same time,

encouraging collaboration and critical thinking (often referred to as "21-st century skills") (Tedre et al., 2021).

Guidelines on how to better design learning programme for young students on AI suggest introducing both AI power and limitations, from a technical and ethical perspective, supporting trail-and-error and reflections (Zhou et al., 2020). Moreover, teachers should be engaged as designers (Zhou et al., 2020) of learning activities in order to overcome the challenge of integrating AI into the standard curriculum (Tedre et al., 2021). For this reason, we collaborated with teachers to co-design an integrated learning programme on AI for 9-12 years old students. It is based on constructionist learning principles and DBL as a way to actively engage children while supporting them in their AI learning journey.

Methodology

This study is focused on the implementation of a learning programme for children on AI. The programme activities are focused on AI big ideas and are integrated with curricular subjects. Our programme is underpinned by constructionist learning principles and includes a DBL activity on AI for good, with a focus on health. Activities were co-designed with a small group of teachers together with researchers as part of a professional learning programme for primary school teachers (Amplo & Butler, 2023). In this paper we specifically want to describe the impact of the programme on students (10-12 years old) in a formal setting, therefore our research question is: [RQ 1] How could we design learning opportunities for students to enable them to creatively and collaboratively explore AI key ideas and competencies within the classroom?

We designed bespoke data collection instruments to gather feedback and insights from both the students and the teacher. Qualitative data were collected through an observation framework which was designed to help the teacher to describe the experience in class. A design journal template was designed and provided to students to be used during the design sessions to keep track of their ideas. And lastly, a semi-structured interview was conducted at the end of the programme with the teacher involved.

The observation framework provided to the teacher consisted of a one-page template that the teacher filed in before, during, and after each session of the programme. At the top of the template, the teacher specified the activity title. Then during the workshop, the teacher was asked to note examples of children's questions or reflections shared during the activity. The last part of the template was focused on a reflection from the teacher written after the session. Some prompts were given e.g., any important aspects to highlight (including feedback on the activity, anything that needs to be changed), one thing your children really enjoyed about this activity. Some of the semi-structured interview questions were listed upfront as a support for the researcher. During the interview, conducted online, the researcher tried to create a comfortable space for the teacher to share ideas. Questions were focused on the programme implementation, on the programme itself, on children's perspective and learning, and on teacher experience in leading the programme. Lastly, a printed design journal was provided to students during the design sessions as a scaffold for the design process. Prompts were written as simple tasks from finding ideas to designing a solution, as listed in Table *1*.

<table>
<tr><th>DESIGN JOURNAL FIRST PAGE</th><th>DESIGN JOURNAL SECOND PAGE</th></tr>
<tr><td>RESEARCH AND DEFINE
Brief description of the problem you would like to solve

Target (for whom)</td><td rowspan="2">PROTOTYPE
Describe your solution in detail
Describe the dataset you need</td></tr>
<tr><td>IDEATION
Our solution (brief description, drawings/ sketches)</td></tr>
</table>

Table 1: Description of the Design journal template

Thematic analysis was the approach used to conduct qualitative data analysis (Braun and Clarke as quoted by Maguire and Delahunt, 2017). Researchers started to become familiar with the collected data and defined some initial codes. Codes were then used to label pieces of data throughout the entire qualitative dataset. The database of labeled data was created using Nvivo® which helped researchers to code and retrieve data (Mason, 2002 as quoted by Ritchie and Lewis, 2003). New codes emerged together with themes that we revised to address our research question. Qualitative data collected were interpreted using self-understanding (Kvale, 1996 as quoted by Ritchie and Lewis, 2003) and cross-sectional analysis (Mason, 2002 as quoted by Ritchie and Lewis, 2003) as we tried to interpret meaning and understanding from the teacher's words (both written and transcribed from the interview) collected during and right after the programme.

Programme design

The programme for children on AI was co-created with a small group of primary school teachers during a professional learning development programme on AI, which was part of an Education and Public Engagement study. During a one-day workshop, after an interactive introduction on AI key ideas online, teachers working closely with researchers, designed activities for children (9-12 years of age) on AI integrated with curricular subjects. To lead the design session the researcher first engaged teachers in a brief introduction on AI for good applications. Then teachers brainstorm ideas on possible subject topics that could be covered using AI tools and ideas. Consequently, in pairs teachers worked to develop lesson plans. To support the design of the lesson plan, the researcher provided a template that included headings for the duration of the activity, tools / materials needed, class management, AI big ideas covered (David Touretzky, Gardner-McCune, Martin, & Seehorn, 2019), subject competencies, and a description of the activity (warm-up – activity – wrap-up). After the co-design session with teachers, researchers worked on creating a prototype of a learning programme for children on AI, described in Table 2. The programme was then led by a teacher in a classroom with primary school students. The first three sessions consisted of activities on AI integrated with other subjects underpinned by constructionist learning principles, while the last three sessions were focused on designing AI for good in the health context. Each session lasted around one hour. The last two sessions were led by the teacher together in the same day.

n.	SESSION	TOOL	APPROACH
1	Unplugged introduction “Farmer robot”	Pen and paper	Constructionism
2	Let’s train an AI model	Teachable machine	Constructionism
3	Machine Learning with blocks	Machine Learning for Kids	Constructionism
4	Let’s design with AI: RESEARCH Define the problem to solve IDEATION	Web Pen and paper	Design Based Learning
5	Concept PROTOTYPE	Machine learning for kids	Design Based Learning
6	TEST/Improve SHARE	Machine learning for kids	Design Based Learning

Table 2: Learning programme outline

The first session was designed to be an unplugged introduction to AI, titled “Farmer robot”. For this activity children should create a decision tree to classify vegetables. Specifically, children received cards representing different-looking carrots and other vegetables and had to design with pen and paper a decision tree that could discern “carrots” from “not carrots”. The second activity was designed to be a hands-on introduction to the machine learning workflow using Google Teachable Machine (Google, 2022). Children trained different models to classify 2D shapes i.e. circles and squares. During the third session children used Machine Learning for Kids (Lane, 2022). With this platform it was possible to train a machine learning model and then implement it in a Scratch-like platform with coding building blocks (MIT media lab, 2022). Children trained models using different datasets e.g. animal sounds.

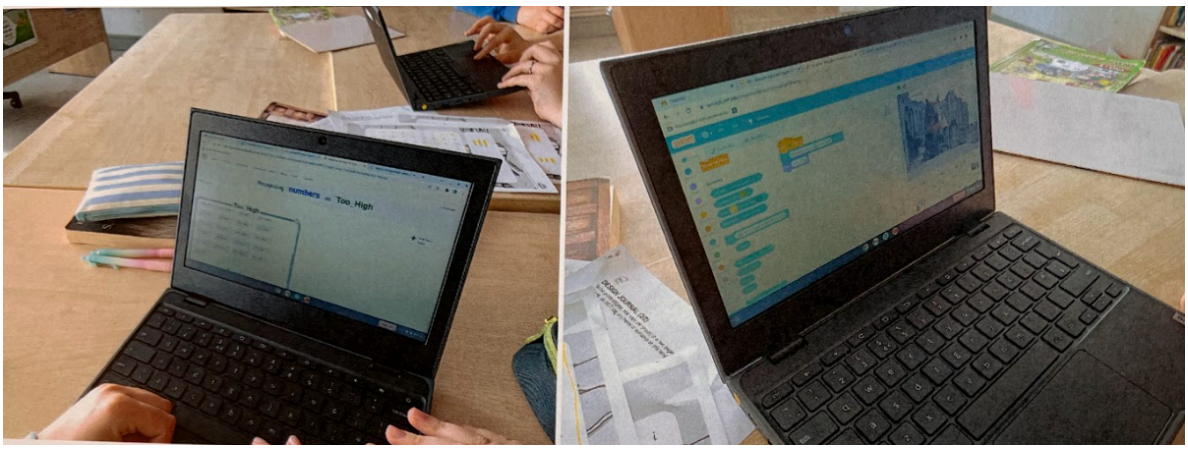

Figure 1: Children working with Machine Learning for Kids training a model during their design sessions

The following three learning experiences aim to engage students in designing a prototype in groups focusing on AI for good to help to solve potential real problems. It was decided to

focus on problems related to health and well-being context. Children went through the entire design process from research to find a problem to solve, from brainstorming ideas to prototyping their solutions using Machine Learning for Kids, Figure 1. Web and video links were provided by teachers to prompt the research phase. Design journal templates were provided to each group of students to guide them through the design process.

Findings and discussion

From the implementation in school emerged that the programme represented an opportunity for children to start to develop their knowledge of AI. Students built their knowledge gradually throughout the sessions. As the teacher told the researcher during the interview while referring to students: *"it just took them a while to think about what they were going to do, you know because they just started, I suppose to think in the AI way"*. It takes time and practice to ignite "AI-thinking". It took a while to start thinking critically about what is behind AI and data and about what could work or not in training machine learning models. It is evident from the teacher's notes in the observation sheets, how students' learning evolved. From the first session, it became apparent that the children started to think about bias meaning and to make connections with their own way of thinking: *"They said they began to see what was involved in AI. They also saw their own biases in terms of orange carrots restricting their results."* Then from session 2 students developed their understanding of machine learning workflow that then led them to reflect on how computers perceive the world, in session 3:

> *They learnt about the stages of training, learning, and testing involved in AI. They also saw the limitations of how a computer sees the world and we talked about how we could so easily distinguish things the computer cannot.*

During the design sessions students develop their critical thinking in relation to AI design: *"There was some discussion about bias in AI and how it could affect health outcomes. There were also further comments on how different our intelligence is from AI"*. Throughout the programme the teacher highlighted how students discussed multiple times how machine "intelligence" and power, up to now, is different from their intelligence and competencies, as humans:

> *The children learnt the stages of developing AI projects. They understood the importance of the data gathering stage. They also saw the ease in which bias was introduced in the training stage. They also realised how different the computer representation of the world was from theirs.*

Knowledge development on AI requires time and practice as AI learning is quite complex. During the programme children developed competencies in terms of AI big ideas from a technical perspective, started to interrogate themselves on ethical issues, and develop skills in terms of new digital tools, as illustrated in Figure 2. As highlighted in the previous paragraph, teachers mentioned how students started to make connections with the real world and to reflect on the meaning of concepts such as intelligence or perception. Therefore, children need more time to build their knowledge with all these new ideas while at the same time becoming familiar with the digital tools. The teacher's notes clearly stated how a longer programme would have been beneficial, *"Possibly have more lead in time to allow students to explore possibilities with AI. They had tasters and were expected to design the whole project."*

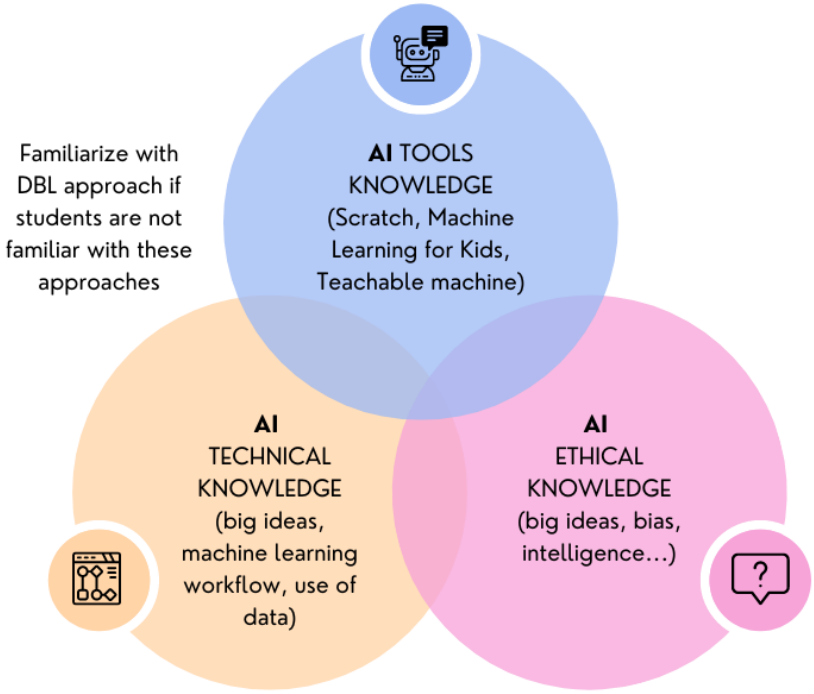

Figure 2: Children AI developing knowledge complexity in the context of learning programme on AI in class

The opportunity to reflect and tinker on AI activities longer could potentially led to less challenging DBL sessions and support the creative aspect children really enjoyed. As indicated by the teacher's reflective observations: *"Overall, they* (students) *said the activities were fun and they enjoyed the creative process, but they did feel that it was a lot to do in designing and building the project in the number of sessions they had"*. In particular, having more time to get used to tools, trying different types of datasets, besides having an introduction to coding with visual building blocks, could help to better prepare students for their experience with design, in which the autonomy and freedom in creating might destabilize:

> *I think they've found difficult with the experience that they had in the things, to then make the leap to make something, you know, or to just come up with an idea to the AI to. So if they had a little more time to play around with their products, you know, with the website, like Scratch as well.*

Despite concerns about the balance between the programme content and time to better prepare children for the challenging design sessions, it emerged from the teacher's voice that students overall enjoyed the experience. Students especially appreciated the group work, playing around with tools, and mostly, as highlighted by the teacher during the interview *"They enjoyed that kind of creative responsibility, I suppose of making"*. DBL represented both a challenging and formative AI learning opportunity for the children. As reported by the teacher in their observation, students *"Enjoyed the responsibility of creating something themselves. They liked having time to research but found thinking in AI terms difficult"*. Design sessions were successful for the three groups of children who worked together to prototype AI for health projects. As mentioned in the teacher's notes *"Eventually they were all able to come up with project ideas"* and *"all the three groups produced ideas they agreed upon"*. One group worked on developing AI software that helps know more about the sugar or fat content of a specific food advising if the values are too high for a specific user, the

second group prototyped an AI-powered tool that could tell the user if a food is considered healthy or not, while the last group focused on designing an AI application that could monitor your sight and advise the user in case of bad or worsening sight as shown in Figure 3. All the students worked actively on their projects, as reported by the teacher, some of them focused on the machine learning model, and some of them work on the interface of their prototypes. They then merged the coding works in one unique application using Machine Learning for Kids platform with visual blocks, as pictured in Figure 4.

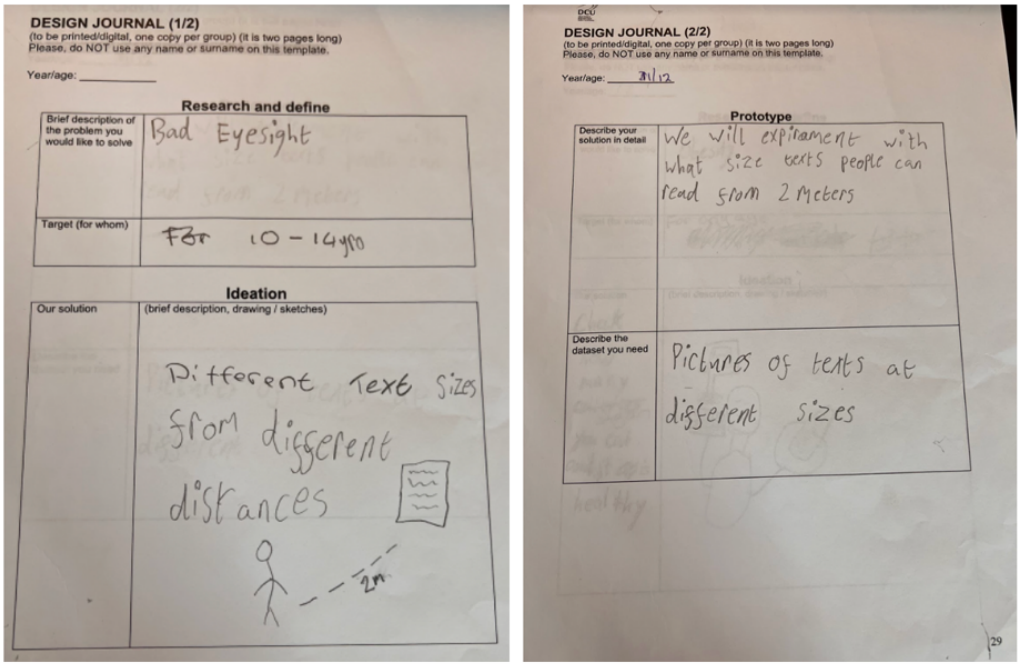

Figure 3: Design journal of a group of students who decided to prototype an AI-enhanced system that can tell you if your sight is good or not

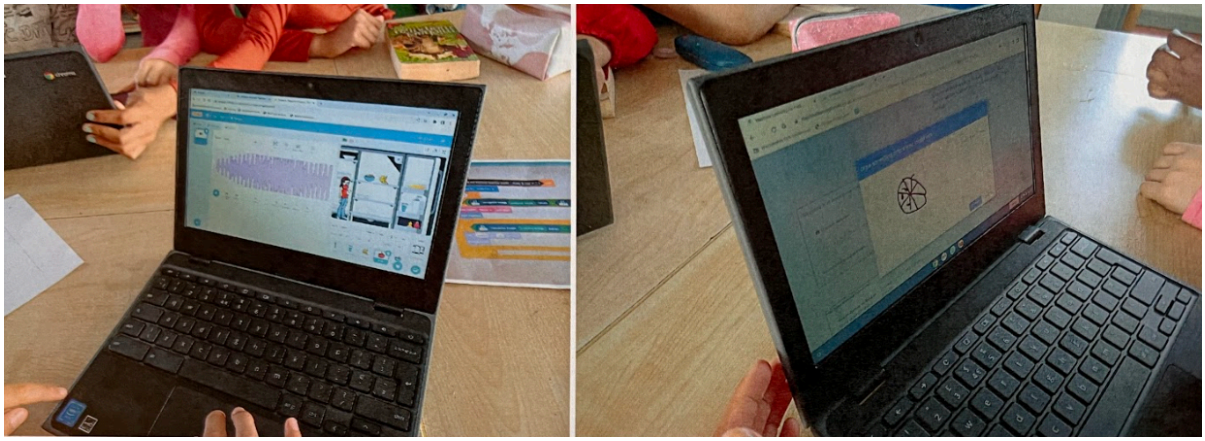

Figure 4: Children working on their AI projects, training a machine learning model on the right and working at a human-machine interface on the left, which was then used to implement the AI model.

When the teacher was asked about their experience in leading the programme the key aspect that emerged was the preparation before the programme. The teacher mentioned that before starting the programme they prepared at home and tested the activities by practicing with the tools "*so I knew how to how to code it and Scratch, you know, how to deal with the blocks that the machine learning was going to come up with*". The teacher also felt empowered to

twist the programme to better fit their students as highlighted during the interview: *"I thought I'd just get them to do something small for us that would work.*". Since the programme was the first opportunity for the students to explore AI, engaging them in exploring machine learning workflow with simple objects available in class felt more comfortable for the teacher and enjoyable for students as a smooth introduction to more complex dataset related to subjects. Lastly, the teacher also autonomously prepared some cards with examples of algorithms in Scratch to manage different type of data (images, sounds) that could be used to test the AI model trained with Machine Learning for Kids, as visible in Figure 4.

Conclusion

It is paramount to engage with children on AI to enable them to recognise both its impact and implication for our society. Students in K-12 should be engaged in AI key ideas (Touretzky et al., 2019) with a holistic perspective (Long & Magerko, 2020) so that they can develop the competencies to become creative, critical, and ethical designers and innovators but most importantly aware 21st-century citizens (OECD, 2021).

Even though our experience was underpinned by the literature on AI competencies for K-12 and design guidelines on learning programmes (Zhou et al., 2020), we wanted to go a bit further and investigate more about the pedagogy of AI. So we asked ourselves, how should we engage students in AI activities? To tackle the research question, we co-designed with teachers a first draft of a learning programme for children, with AI integrated activities and DBL sessions on AI for good. Both constructionist learning principles and DBL approach supported children in being designers and agents of their own learning of AI. Students showed they enjoyed the responsibility of creating something new and collaborating in groups even if they found at the same time the task slightly challenging. Therefore, despite being creative in AI requested extra effort, on the other hand, DBL fostered the development of knowledge on AI by providing students an opportunity to reflect and think about AI. DBL sessions on AI for good supported students' teamwork and collaboration while encouraging communication, creative and critical thinking.

Our experience in school demonstrates the potential for a more extensive and long-term programme that could engage students in developing an understanding of the big ideas in AI. Not only as part of computer science programme but also integrated with curricular subjects. AI domain allows for many connections with both STEM, non-STEM subjects, and the real-world that are worth trying to investigate further. Moreover, next to the content, we would like to draw attention to the pedagogy of AI that is only starting to be addressed. In this regard, teacher efforts in twisting the programme and preparing supporting material beforehand demonstrated how the teachers' role is key in engaging with students. Therefore, we would like to encourage research groups working on AI, to focus their Education and Public Engagement actions also on teacher learning and to co-design with teachers to better co-create learning programme for children that could promote AI knowledge, and positive and aware use of this technology already part of our lives.

Ethical approval

This study is part of a broader research study that was granted ethical approval by the Dublin City University Research Ethics Committee, reference number DCUREC/2021/043.

Acknowledgments

This study was supported by Insight Centre for Data Analytics, Ireland with the collaboration of PDST (Professional Development Service for Teachers).

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