INSPIRE: FOURTH INDUSTRIAL REVOLUTION TEACHING IN THE CLASSROOM

A MULTI-DISCIPLINARY COLLABORATIVELY DESIGNED PILOT PROJECT

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Abstract

The INSPIRE pilot project provides core evidence on key interventions and CPD needs to enable a 4IR (Fourth Industrial Revolution) curriculum within secondary education. The project builds on an inclusive approach to inform further research proposals to impact and transform the education sector.

Across the UK, there is currently no systematic pedagogical design or evaluation to support interdisciplinary teaching and learning to include 4IR skills and knowledge. There is also no clear national strategy for schools and FE colleges to follow in how to embed 4IR, including Artificial Intelligence, Robotics and Internet of Things tools, skills and understanding into their teaching. Such a lack of an evidence-based research study impacts our young students in particular and education system in general, and further discriminates against disadvantaged and digitally excluded groups.

The INSPIRE pilot study applied a design-based research methodology framework and worked with two London-based schools to co-design and deliver a series of workshops to Year 9 (13–14-year-old) students introducing them to Artificial Intelligence, Robotics and Internet of Things skills through engaging practical activities.

Within the pilot study we engaged with both co-designers and students to capture opinion, understanding, learning and enjoyment before, during and after the workshops. The significance of this paper is twofold; to identify lessons learnt in developing 4IR skills and knowledge within the curriculum and to share the insights of the adults and young learners throughout the project.

Keywords: 4th Industrial Revolution, Artificial Intelligence, Internet of Things, Robotics, Pedagogy.

1 INTRODUCTION

We are living in unprecedented times; the fourth industrial revolution (4IR) has been signalled over the past decade by a swathe of ground-breaking emerging technologies.

It is predicted that by 2025, 15% of the workforce is at risk of 4IR-related disruption, with 6% of workers being fully displaced and machine work-hours matching that of human workers[1]. Job creation is beginning to lag behind job destruction, exacerbated by the COVID-19 pandemic and increasing moves to online and alternative working, those already disadvantaged by gender, race, social movement or other demographic indicators are going to find progressing in the job market even harder when challenged by 4IR technologies and advancements.

While there are elements of work to be done in the current, existing and developing job sphere, it is the place of the educators to ensure the current and emerging generations are ready for the workplace that they will find themselves in[2]. This paper primarily focusses on the UK educational system. There was significant reform in the educational system from 2015-17 with new GCSE's, AS and A-levels (terminal national exams held at ages 16, 17 and 18 respectively). None of these reforms introduced 4IR into the classroom in anything more than a passing reference to emerging technologies and the structure of the UK educational system leaves little opportunity for teachers to teach outside of the mandated material. While higher education institutions may be slightly more prepared[3] the opportunities afforded to younger students, with an opportunity to engage, excite and shape futures, is virtually non-existent.
This pilot study was designed to explore this problem by offering a range of 4IR workshops to year 9 students (roughly 13 years old) in two South London secondary schools. The material was co-designed with the teachers and delivered across seven sessions of between one hour and a whole day each. The initial groups consisted of a total of 45 students, 15 in one school and 30 in the other, although attendance varied due to interest, demands on the students' time by other elements of their education, and the challenges of COVID-19.

2 METHODOLOGY

2.1 Co-Design

We decided to use a co-design approach for the pilot project. This supported us in collaboratively solving the challenges of designing three separate strands of 4IR learning events[4]. Co-designers included Computing and Design & Technology teachers from the schools and a further-education college, colleagues from industry (including the developers of the Mars rover simulator), and a number of Higher Education academics with experience in 4IR technologies and design-based research.

2.2 Multi-Disciplinary Approach

4IR technologies are heavily focused around Computing developments. However the benefits of 4IR technologies are felt across all industries and rarely in isolation[5]. When developing the pilot study we therefore intended to involve teachers from as many subjects as possible. However, availability and the restrictions of the then still emerging COVID-19 pandemic led to limitations; we were joined by a Maths specialist, a Design & Technology specialist, and a number of Computer Science specialists.

2.3 Design-Based Research

We used a design-based research (DBR) approach; DBR is a concentrated, collaborative, and participatory approach to educational inquiry. The process of DBR involves developing solutions or interventions to problems[6]. An “Intervention” is any interference that would modify a process or situation. This pilot project represents the first iteration, with further research to be addressed in future iterations based on the lessons learnt and challenges faced in this iteration.

One positive aspect of DBR is that it can be employed to bring researchers and practitioners together to design context-based solutions to educational problems which have deep-rooted meaning for practitioners about the relationship between educational theory and practice[7]. In the INSPIRE project, production stakeholders have been involved in the co-design of the educational resources through its different streams. The project was divided in three main streams:

- Robotics – utilising a Mars Rover simulator[8]
- Artificial intelligence (AI) – developing the use of machine learning through handwriting recognition
- Internet of things (IoT) – using Arduino's to build and use small circuits.

One key aspect is that current teaching approaches in the three streams are fragmented and do not bring together the multidisciplinary stakeholders (including teachers and industry) that are needed to address the pedagogical, curriculum, knowledge, tools, and skills. Banks and Barlex discuss the problems of siloed education and it leading to students' inability to "develop a systematic comprehensive view of the world around them"[9] at a fundamental level. The co-design process, with key production stakeholders, provides an evidence-based approach through requirements gathering, creation of resources, design of evaluation framework, sharing of findings and dissemination.

DBR provides a significant methodological approach for understanding and addressing problems of practice, particularly in the educational context, where a long criticism of educational research is that it is often divorced from the reality of the everyday[10]. DBR is about balancing practice and theory, meaning the researcher must act both as a practitioner and a researcher. A series of co-design workshops brought together the production stakeholders to develop shared knowledge to rethink the curriculum. The project has included the following external partners besides the Univeristy team:

- An AI consultant with experience of delivering introductory workshops.
• Cyberselves Universal Ltd, a company developing robotics software and educational resources.

• Harris Academy Orpington & Harris Girls Academy Bromley, two London-based secondary Academies with high numbers of students identified as pupil premium (i.e. under-privileged).

• Milton Keynes College/Institute of Technology.

• The National STEM Centre.

• MKAI and Cisco - small and large industries.

We held a commencement meeting in February 2021 in which we discussed the overall aims and objectives, the streams, and aligned desires with realities in terms of what could be developed and delivered, in terms of content, and by whom. This was followed by four sprints in March focusing curriculum coverage, areas for development and problem solving. This resulted in each stream having three sessions, a one hour after-school club followed by a drop-down day for each with two sessions totaling six hours per day. May was used for resource development. The robotics stream was run in early June, AI in late June and IoT in early July. A final session was held with all students together in mid-July wherein students developed a 4IR solution to a problem and presented it to a panel. A total of 45 students (15 from Orpington and 30 from Bromley) were initially signed up to the program, though actual number engaging varied over the course of the pilot study.

2.4 Evaluation framework – production stakeholders

Production stakeholders were asked to fill in pre-project and post-project questionnaires. Both quantitative (Likert) questions and qualitative open-ended questions were designed to capture differences in perceptions about the knowledge, digital skills, curriculum and challenges before and after the project.

The survey for partners was designed to capture an understanding of:

• Personal knowledge on the different topics.

• Digital skills of students.

• Teaching and learning curriculum.

• Key challenges for learning the different topics.

The results are discussed in section 4.1.

2.5 Evaluation framework – students

Students were also asked to fill in a pre-project and post-project questionnaire which, again, included both Likert and open-ended questions. However, students were also asked to complete three very short questionnaires during the delivery of each stream, following a reflective journal approach. A reflective journal is an account of students work in progress, but more essentially an opportunity for reflection on the learning experience. The intent of a reflective journal is to provide students with a means of engaging critically and analytically with the educational content[11]. For that reason, four questions were repeated for each session:

• What was most interesting in this session?

• What is the best thing that you learned in this session?

• What was most challenging in this session?

• What would you like to do next (in relation to today’s session)?

To ensure anonymity students were assigned unique ID numbers at the start of the project. We had no way of correlating ID numbers with individual students, although numbers up to 15 were assigned to Harris Academy Orpington students, and above 15 to Harris Girls’ Academy Bromley students. The results are discussed in section 4.2.
3 DELIVERY

The three streams of robotics, artificial intelligence and the Internet of Things were decided on as impactful areas which can be identified in emerging career roles and in recently developed University courses. There was discussion amongst the co-developers as to the best approach to delivering the content; while the group wished to run the project over a significant period of time, interleaved with the regular curriculum, the needs of the school, availability of partners and restrictions of COVID-19 this had to be compressed into three full days. The addition of three so-called clubs was agreed as a soft entry into each stream. Each stream had a leader; the AI stream was led by an external consultant with experience of developing AI workshops for older learners, the robotics stream was led by Cyberselves, and the IoT stream was led by two members of the University team. The Bromley school delivered the material themselves through their in-school staff and one of their internal consultants. The Orpington staff were much newer to the school, so a member of the team went in to support during the drop-down days and an internal consultant supported during the club sessions.

3.1 Robotics

Cyberselves developed a Mars rover simulator which ran in a browser (see Figure 1.) and was programmed using a block-based language. There were five missions (all to find water) with varying difficulties (mainly how far the water was located) and challenges (such as boulder fields and sandstorms). The club session was led from a presentation on the interactive whiteboard. Students were introduced to the project as a whole and then had some discussion as to what a robot is and their purposes. They were introduced to the simulator and some of the things it could do, and finally engaged in a discussion as to other robotics-based jobs.

The drop-down day had a workbook which was printed out for the students in advance. There was a range of activities to complete offline (such as drawing a robot, identifying what made it a robot, identifying aspects of the robotics sense-decide-act loop within their robot) and prompts to complete the simulation levels. Each prompt included demonstrations of the new blocks that could be used and tips for completing the challenges. There was also a section encouraging considerations of the ethical impacts of using robotics.

During the day the students were also shown a number of videos on robotics and engaged in a lively discussion on the ethics of robotics.

3.2 Artificial Intelligence

The Artificial Intelligence sessions were delivered via Google Docs and included the use of Colab-based notebooks[12] which enabled students to read contextual information and then either run, or
edit then run, Python code within the cells to build, train and then run AI models that analysed a set of hand-written numbers (See Figure 2.) provided by a publicly accessible data-set, and explore varying parameters to try and make the model as accurate as possible at predicting the actual value of previously unseen data.

Students were also introduced to the concepts of neural networks, hidden layers, and a range of other key terminology both through the documents provided and through a number of videos shown during the sessions. Videos also covered some of the uses of AI including medicine and the sciences and a discussion was held on the ethical impacts of using and relying upon AI-based decisions.

3.3 Internet of Things

The Internet of Things workshops were perhaps the most technically challenging of the workshops to develop, as the students were going to be building and programming physical circuits. This involved a significant investment, and the opportunity was taken to donate the hardware to the schools to enable future use. As the hardware was not able to be provided in time for the club sessions, these were split between videos of IoT solutions and question/discussion sessions on the use of IoT including some ethical debate and some discussion on cross-subject use of IoT in schools. With the hardware now available, the drop-down day was a significant booklet which talked the students through how to use the Arduino software and four tasks ranging from blinking an on-board LED to connecting to the Internet and logging data to a remote service. Each task had a number of attendant challenges. There was also an overview of a number of extra sensors provided to encourage students to explore

![Figure 2. Handwritten 6 broken down to pixels for AI analysis](image)
additional possibilities. One school was provided with a 4G wireless router to allow Internet access while the other was relying on mobile phone hot-spotting.

4 DATA ANALYSIS & RESULTS

The data collected was from a range of questionnaires completed by students and production stakeholders before, during and after the project. All data was cleansed, and student data was collected anonymously, correlated by ID number only.

4.1 Production stakeholders

Production stakeholders comprising of school staff, University staff, the AI consultant and colleagues from Cyberselves, completed two questionnaires, one prior to the project and one after the project. There were nine responses to the initial questionnaires and six for the final questionnaire. These are primarily open answer qualitative questions. Key points are shared in this section, with the results of a thematic analysis on the post-project evaluation shared in the appropriate sub-sections.

4.1.1 Personal Knowledge

Production stakeholders reported that they had knowledge, or at least some knowledge, of all three streams, although there was the most confidence in robotics.

4.1.2 Digital Skills

Partners were asked about what digital skills students should possess. Although the responses are quite varied, a general theme of computational thinking and problem-solving skills can be seen, as well as general IT skills such as typing, cyber-security and digital literacy. The ways of gaining these skills are again varied, but include both formal and informal teaching, sandboxed opportunities to explore with perceived costs of failure, and predominantly lots and lots of practice.

Broadening the range of availability divided stakeholders predominantly into two camps; one suggesting development of resource and activity and one suggesting development of curriculum and investing in the development of competent teachers. All production stakeholders identified the need for 4IR skills in the emerging workplace and that by developing skills now the students will become more employable in the future.

4.1.3 Curriculum

Figure 3. shows the perceived impact of 4IR technologies on subjects within schools. Maths, Sciences, Design & Technology, Citizenship and Computing are all seen as being highly impacted, while English, History and Modern Foreign Languages are seen as being only slightly impacted by IoT and Robotics (though still highly impacted by AI).

All production stakeholders believe that there should be more cross-discipline teaching to aid not just learning about 4IR technologies, but to better reflect the world the students will be working in.

Production stakeholders felt that 4IR technologies should be integrated into as many subjects as possible, but in particular:

- Robotics into Maths, Sciences, Design & Technology and Computing.
- AI into the same as Robotics, but also Citizenship, PE, Geography, Sociology, Law and Modern Foreign Languages.
- IoT into the same as Robotics as well as Geography.
4.1.4 Challenges

Finally, production stakeholders were asked about the perceived challenges faced in introducing 4IR technologies. In terms of robotics the biggest challenges include the cost of physical robotics and the difficulties in correlating abstract and real-life ideas. AI is seen as challenging due to the technical nature of the subject and difficulty in comprehending the foundations, as well as accessing the computing power needed for a lot of AI. IoT has the challenge of needing hardware (although stakeholders showed differing opinions as to whether it is affordable or very expensive!) and the resilience of dealing with things when they don’t work. All three streams face challenges in terms of teacher expertise and a curriculum (and resources) which do not support the teaching of the technologies.

4.1.5 Post-project – Robotics

Production stakeholders believe that the students enjoyed the relevance and maturity of the Mars Rover simulator; thematic coding revealed enjoyment as one of the prevalent outcomes. They enjoyed seeing future potential for robotics. However, it was identified that the tasks for the students were limited and somewhat unspecific; it was suggested that shorter, sharper tasks, more documentation and some pre-written programs could have helped. The similarity of the tasks also challenged some of the students’ attention spans. Thematic coding of the questionnaire shows that the students struggled with the lack of appropriate programming skills; most had done no programming, though a few had used Scratch in primary school.

4.1.6 Post-project – Internet of Things

Production stakeholders generally saw engagement with the physical devices and the opportunity to be hands on as positive elements; this was one of the prevalent themes from the thematic evaluation. There were comments as to students struggling with using a booklet and needing to be guided through the tasks by the teachers, as well as some of the hardware not working as expected and a need to troubleshoot which the staff were not always able to do. The issues caused by improper preparation of the network and some of the difficulties with using the hardware revealed themselves as the dominant theme.

4.1.7 Post-Project – Artificial Intelligence

Production stakeholders saw that students enjoyed the feedback and challenge involved in improving the accuracy of the AI model. They gained an insight into the technical difficulties and the future
potentials of AI and really enjoyed the ethical debate. The theory of artificial neural networks, and particularly the maths, was too text heavy and above the ability of the students. This was by far the most predominant theme identified in the thematic analysis.

4.2 Students

While the intention of the project was to have the same students throughout all sessions, some opted out during/between sessions, some had additional requirements on their time due to schooling and some were unable to attend due to COVID-19 related issues. There is insufficient room within this paper to detail all of the open-ended comments from the students, which were both detailed and enlightening. However, summaries have been included below for each of the three streams.

4.2.1 Robotics

There were 34 responses to the initial questionnaire and 24 to the terminal one. Of these, 16 students initially claimed to be less than knowledgeable about robotics, 15 were neutral and 2 were knowledgeable - this improved to 7 neutral, 14 knowledgeable and 3 very knowledgeable at the end. Initially 32 were interested and 31 were excited to learn about robotics - this dropped to 11 interested (and 4 not interested) and 19 excited to learn about the subject at the end. One student was initially very frightened about learning about robotics, with the rest spread between not frightened and neutral - none were frightened at the end. None thought robotics would be unimportant in their future lives and 12 thought it would be very important; by the end 21 though it would be important or very important in their future lives.

There were 29 respondents to the first robotics questionnaire (for the club), 38 for the second (part way through the day) and 35 for the third (at the end of the day). Students found learning to use the simulator and avoiding the various obstacles interesting, as well as the various ethical debates around impact on the workforce, the basic structures of robots, and the impact that robotics (and their in-built biases) have, and will have, on our lives. They most enjoyed learning about the amount of data robots need to handle, the amount robots do and the difference between robots and robotics. They enjoyed learning shortcuts and new parts of code. One student enjoyed learning resilience, and a number mentioned enjoying learning about our dependence on technology and the videos demonstrating robots carrying out surgery.

The challenges students faced including having to explain answers and thinking deeply, carrying out the Rover challenges (finding water) and avoiding crashing. Some of the students found the outcomes of the ethical debates - such as the wider impact of Robotics - challenging; many want to learn more about robotics, program and assemble their own robots and learn more about the real Mars rover.

4.2.2 Internet of Things

There were 34 responses to the initial questionnaire and 24 to the terminal one. Initially 19 students claimed to be less than knowledgeable about IoT, 11 were neutral, 3 were knowledgeable and one claimed to be very knowledgeable; this changed slightly with 2 students feeling less knowledgeable at the end, and one extra feeling very knowledgeable. 25 were interested and 24 were excited to learn about IoT. One student lost interest and excitement about the subject at the end of the project. One student was frightened about learning about IoT, with the rest spread between not frightened and neutral. This was maintained at the end, with more saying they were not frightened at all. Two thought IoT would be unimportant in their future lives and 11 thought it would be very important. No students thought IoT would be unimportant by the terminal questionnaire.

There were 26 responses to the first IoT questionnaire (for the club), 32 for the second (part way through the day) and 29 for the final one. Student enjoyed learning about the uses of IoT in the world and how they have been developed. They found building circuits interesting, figuring out what the code did and learning how the different parts works. They enjoyed making things happen with their circuits, forming their own projects and learning about the impacts of IoT inaccuracies and malfunctions.

Students struggled to follow some of the projects and found the robustness required when things did not go right to be challenging. Most want to do more projects with a simpler introduction, and many expressed a wish for more ethical debate.
4.2.3 **Artificial Intelligence**

There were 34 responses to the initial questionnaire and 24 to the terminal one. Initially 20 students claimed to be less than knowledgeable about AI, 10 were neutral and 4 were knowledgeable - this improved to 11 neutral, 8 knowledgeable and 5 very knowledgeable. To start with, 27 were interested and 25 were excited to learn about AI - these numbers were roughly maintained. 1 student was very frightened about learning about AI, with the rest spread between not frightened and neutral. There were an additional 2 slightly worried students in the terminal questionnaire. One thought AI would be unimportant in their future lives and 12 thought it would be very important. More students (13) out of a smaller sample size felt that AI would be very important to their future lives in the terminal questionnaire.

There were 34 respondents to the first AI questionnaire (for the club), 33 for the second (part way through the day) and 20 for the final one. Students found the uses of AI - including in speech recognition and social media - interesting. A number found artificial neural networks (ANN) interesting despite the difficulty of the maths involved, as well as the ethical debate. Their favourite things to learn included the uses of AI in Google Quick, Draw[13] and its ability to recognise images, increasing accuracy in a neural network through adjusting parameters, the use and misuse of captcha images and the uses of AI in healthcare.

One student raised an interesting point about the challenge of differentiating between AI and programmed results. Some struggled with ANNs but more struggled with coming up with interesting arguments in AI ethical debates. Students want to learn more about AI and ANNs and build their own AI-based models. Some want to link AI to how robots think.

5 **DISCUSSION**

There were many challenges within this pilot project, including illness within the project team, compressed time frame. Working with young people brings its own difficulties in terms of inexperience, behavioural issues and attention spans. Many of these are reflected in the feedback (particularly from the partners) suggesting the resources needed to be simpler, broken down more and less wordy; the project pan called for co-design, but it is evident in retrospect that more input at the testing stage was needed from the teacher co-designers rather than those of us more used to designing learning material for adults.

There were also some comments which are difficult to drill down into without further research; if students are struggling to work from a (relatively simple) workbook of written instruction there is a debate to be had as to whether the resources should be changed or whether this is an important life skill which deserves to be taught to the students.

However, there are many positives from this project; in the final session a number of the students were brought together and asked, in a short space of time, to identify a problem that could be solved with 4IR technologies and present their proposed solution. Problems ranged from food supply problems to volcanic eruption detection and some novel solutions. While some students identified less enjoyment for the streams in the terminal survey, many others moved their enjoyment, interest and self-assessed knowledge to a higher level than it was at the start of the project.

6 **CONCLUSIONS AND IMPACT ON FUTURE RESEARCH**

This was always meant to be a pilot project, and this short report has only picked up on the central learning points we have gained from this pilot; the following points will form the core of interventions for future research:

- Co-design needs more input from the co-designers; feedback from production stakeholders identifies areas of improvement, such as within the resources, which could and should have been identified by the co-designers before being put in front of students.
- Students see the importance of 4IR technologies in their future lives and have an interest in learning more about them.
- Students enjoy participating in ethical debates and future research should aim to capture these discussions - and the key points - in some way.
Some aspects such as artificial neural networks were reviewed only negatively by production stakeholders; however, while some students identified that these were extremely challenging, they also identified a desire to learn more. Future research could look at building on this while allowing simpler comprehension as well extending the learning. We could also look at bringing some learners on board as co-designers.

Students struggled with long sessions and long written instruction. Future research should work on maintaining interest; this could be by running shorter sessions over longer periods of time or more effective decomposition of the longer sessions. It should also be considered whether either a different pedagogical approach should be taken or whether better instruction in applying the current approaches is called for.

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