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PELARS: Incorporating Universal Design Principles in the Development of a Learning Analytics System for STEM Education

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PELARS – Incorporating Universal Design principles in the development of a Learning Analytics System for STEM Education

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Abstract

PELARS (Practice-based Experiential Learning Analytics Research and Support) is a three-year research project funded under the European Union's Research and Innovation programme, FP7, and involves twelve partners across Europe drawn from both academic and industry sectors. It is a collaborative multidisciplinary project that seeks to innovate at the intersection between design, technology and education. The aim of PELARS is to develop a Learning Analytics System (LAS) and integrate this system into a physical embodiment (furniture and/or environment) suitable for three proposed learning contexts; secondary or high school STEM (science, technology, engineering and mathematics) education, third-level interaction design education and third-level engineering education. Common to each of these learning contexts is the emphasis on practice-based experiential learning and the use of programmable learning kits. With such a wide range of potential user variables and requirements, a universal design approach was taken to ensure the resulting learning environment can be interpreted and interacted with by as many users of varying physical and ability profiles as possible. This paper explores the challenge of specifying, designing, prototyping and evaluating such a project with a universal design approach and describes the thinking and methods employed in order to ensure adherence to the relevant principles and guidelines. The outcome of the project seeks to incorporate best practice in universal design so that the result is a fit-for-purpose LAS system, supporting kits and materials, relevant curricular activities and suitable furniture and environment in which to implement these.

Keywords: Practice-based Experiential Learning Analytics Research and Support (PELARS), Science, Technology, Engineering and Mathematics (STEM), Learning Analytics System (LAS), Universal Design (UD), Graphical User Interface (GUI), programmable kits, technology integration, Task Furniture in Education (TFE), curriculum development, policy change.

PELARS – Incorporating Universal Design principles in the development of a Learning Analytics System for STEM Education

The PELARS project seeks to promote and encourage the learning of STEM subjects through practice-based learning. It is not the intent of the project to teach or disseminate the principles of Universal Design (UD). However, by considering the principles of UD in the development of the relevant aspects of the PELARS system, we hope to achieve an engaging, accessible educational tool that is useable by anybody who wishes to interact with it. The intention at the outset is that the UD aspects of this project should be invisible – in a successful implementation of UD within the project, a user, regardless of age, size or ability should be able to access, interact and navigate through the various usage scenarios of the system without being consciously aware that their specific requirements have been taken into account. This paper, therefore, is not concerned with the teaching of UD principles, but documents how these principles have been used as a guide in the design of a teaching and learning analytics system for STEM subjects. The paper will firstly give a brief description of the PELARS project, outlining the project structure, aims, intended users and proposed outcomes. As the proposed project outcomes, and the methods of achieving these, are wide-ranging and multi-faceted, the principles of UD do not apply to every aspect of the project. The limitations and project areas to which this paper apply will be clarified below as well as the usage context and user requirements. Each of the following areas: furniture and environment, Learning Analytics System (LAS) and the Arduino Talkoo kit with associated Graphical User Interface (GUI) will be examined as potential areas for implementation of the UD principles. The impact on the design of the above areas from the requirements generated by the proposed user groups will be discussed and the consideration of UD principles in the resolution of a cohesive design will be outlined.

Background

Project Outline

PELARS is three year, EU funded, FP7 project investigating how teachers, learners and technologies can support one another in the hands-on learning of science, technology, engineering and mathematics (STEM). The project commenced in Feb 2014 and runs until Feb 2017. The National College of Art & Design (NCAD), Dublin are one of 12 academic and commercial partners spread throughout Europe and are leading Work Package 3: Furniture and Environment (one of eight work packages within the project) which requires the provision of academic input into the research, design and evaluation of the furniture and environment elements of the project. Involvement in the project builds on NCAD's successful completion and co-ordination of Task Furniture in Education (TFE), a previous four year FP7 project conceived and structured to research and develop new and innovative task furniture solutions addressing modern advances in teaching and learning, the integration of technology in the classroom and the postural implications for children and young adults in schools.

The main aim of the PELARS project is to develop a LAS and incorporate this into a specifically designed piece of furniture or environment suitable for application in the proposed learning contexts detailed below. The intended users are primarily learners, teachers and researchers but also include facilities managers, cleaners and IT technicians.

The value of the project is manifold: as well as the LAS itself, learning kits, materials and the supporting environment, the outputs of the LAS seek to inform students, teachers and researchers as to what and how students are learning while engaging in hands-on education in STEM subjects. It is intended that this knowledge can be used to develop curricula and motivate policy change regarding the teaching of these subjects.

Limitations of this paper

The proposed outputs of PELARS include (but are not limited to) the following; furniture and environment, learning analytics system, Arduino Talkoo Programmable Kit, learning kits, sensing technologies, GUI, mobile-generated content, learning analytics data for research, curricular development, policy change, scientific dissemination and commercial exploitation. Because of the scope of the project, at the outset, we recognise the limitations of this paper in detailing the UD aspects relevant to each of these project output areas. Therefore, this paper focuses on the areas of furniture and environment, the learning analytics system and the Arduino Talkoo programmable kit, as these are the most pertinent outputs in terms of the application of UD principles.

Implementation of UD principles: opportunities and challenges

There is an obvious challenge associated with the incorporation of UD principles in a project with such wide ranging outputs and such a diverse range of multidisciplinary partners with both academic and commercial interests. PELARS is both a research and a design project in that while the initial stages of the project require desk and laboratory based research, the ultimate aim of the project is to embody the outcome of this research by designing a fit-for-purpose learning analytics system that has been tested "in-the-wild" with the intended range of user groups and has been iteratively modified through rigorous prototyping and evaluation phases. This combined research and design approach coupled with a strong focus on primary research through user testing presents an opportunity to successfully implement UD principles within the project. However, the scale of the project and the diverse range of research and design methodologies employed by the various partners also poses challenges to ensure consistent application of UD principles across each of the project outputs.

Project context

The consideration of both a general practice-based learning environment and specific learning contexts as defined by the PELARS project, alongside the various user groups associated with these environments and their specific needs has helped guide a user-centred research and design process that also aligns with UD principles. This section outlines the key considerations in each of these areas. It is worth noting the titles of the seven Principles of Universal Design at this point:

Principle 1. Equitable Use

Principle 2. Flexibility in Use

Principle 3. Simple and Intuitive Use

Principle 4. Perceptible Information

Principle 5. Tolerance for Error

Principle 6. Low Physical Effort

Principle 7. Size and Space for Approach and Use.

Learning environments

In general, environments where practice-based experiential learning takes place combine physical factors such as furniture, lighting, acoustics and intangible factors such as engagement, collaboration and social interactions. Within the PELARS project there are three proposed learning environments; secondary or high school technology classes, third-level interaction design and third-level engineering courses. Each of these contexts has its own particular requirements due to the variance in class structure and duration, course or project content, materials and processes used, teaching methods, user profiles and physical environment. By analysing each of the particular context requirements through the prism of UD principles it is intended that the resultant needs can be identified, prioritised and addressed in the development of a design solution.

User groups

Each of the learning contexts above will need to successfully accommodate a wide range of users of varying ages, abilities, learning stages and cultural backgrounds. When we say 'user' in the context of PELARS we are concerned mainly with the primary users - students and educators. Given that the potential age range of learners within the above contexts spans from twelve years old to adult, the project challenge is to design a system that takes into account varying levels of experience, proficiency and maturity as well as the attendant range of physical sizes and abilities.

Also, while the system will predominantly be used by learners and teachers, potential users will also include researchers, facilities personnel, IT technicians, cleaners and anyone who may interact with any element of the system over its life cycle. Recognition and consideration of the needs of every level of user at the outset of the project will help ensure the design solution is consistent with the expectations and intuition of each user group.

User requirements

In the first year of the project, Work Package 3, Furniture and Environment produced the report 'Requirements Analysis Report D3.1'. This report related to the physical, furniture and environmental, educational and social requirements of learners and educators within practice-based experiential learning environments. The primary goal was to inform a user-centred design process that could develop effective learning experiences for a wide range of users and associated requirements. Whilst there is a large range of potential users groups (detailed in the previous section), this report identified learners and educators as primary users and focused on their well-being as the primary user requirement in the context of practice based learning. Well-being was seen to directly relate to learning ability and style, posture, physical activity, personality-type and body-brain connection. These 5 key user requirements are considered below:

Learning Ability and Style: Every learner processes new information in different ways and can adopt a variety of cognitive learning styles during the learning cycle. The PELARS project embraces Kolb's cognitive learning styles which are defined as - Accommodating, Assimilating, Converging and Diverging (Kolb, 1984). Learners can move between these learning styles and the furniture and environment should cater for both diverse forms of learning and also the transition between styles.

Posture: In a practice based learning scenario, learners and educators move between four main postures – reclined sitting, 90-degree sitting, open angle sitting and standing. The design of the seating and work surfaces should support this range of postures.

Physical Activity: Practice-based experiential learning by its nature inherently incorporates activity and movement. There is also an increased awareness of the damaging effect of prolonged sitting with physical inactivity now identified as the fourth leading risk factor for global mortality (WHO, 2010). This user requirement for physical activity suggests an approach to the design of the learning environment that successfully integrates physical activity. It also points to a need to recognise and design for the diverse range of physical abilities within the broad user base outlined above.

Personality type: The learning environment will host a wide range of personality types. Some students may thrive on interaction with their peers, while others may need solitude to process information. The design of the learning environment needs to support both individual and group learning with varying levels of connection between peer learners and between learners and educators.

Body-brain connection: There is evidence that movement is not only healthy for postural development but can also have a positive effect on a person's ability to concentrate, focus and absorb information (Thomas, 2009). Addressing this connection between body and brain activity, office furniture designers such as Knoll have used this ergonomic consideration as a key element in their design process. In their work, they emphasise the need to consider more than the physical needs of the user, suggesting that designers must be aware of and design for the cognitive nature of office work (Springer, 2010).

Whilst not driven entirely by UD principles, these user requirements have helped to engender a design approach for the project that prioritises the physical and mental well-being of primary users whilst catering for a diverse range of learning approaches and abilities. In this sense, they can be seen to align with general principles and goals of a UD process.

Current Design

Design intent: Furniture and Environment

The intended application of the PELARS project is ultimately to create an environment within a learning scenario in which the actions of the learner (or group of learners) can be analysed through sensing technologies integrated into the fabric of the environment and furniture within it. The data generated by the sensing technologies can be correlated with learner generated data (through feedback devices and mobile device generated content) and represented in a graphic visualisation of the learners' individual session. The teacher or facilitator will have visibility of all the individual learner sessions running at any one time through a graphic visualisation and can monitor and respond to the progress of each learner group. The furniture and environment therefore has to support the integration of the various technologies required and present them to the users in an equitable, accessible and useable manner. Application of the principles of UD through the concept and development process has been useful to reveal potential user needs which can then be incorporated into the design. The following sections illustrate how some of the UD principles have helped guide design decisions taken during the development of the furniture and environment.

Furniture Design

The discussion below regarding the furniture design recognises that the PELARS project is just past the halfway point in duration and thus any design referred to is subject to modification in the overall development of the project. In order to discuss the application of UD principles to the design of the furniture, it is first necessary to describe the features of the present configuration.

The current iteration of the furniture (see Fig. 1 in Appendix A) consists of a 1,100mm wide, D-shaped height adjustable table and a separate stand which contains the technological components. The stand comprises of a vertical steel pole which is fixed to a base plate mounted in a square ventilated box which sits on the floor. This pole and baseplate provide the structural support for the other components. The computer required to power the LAS is mounted in the ventilated box. Mounted on the steel pole at a height of 620mm and running to 1800mm are two 1,100mm wide whiteboards separated by a 200mm wide support structure, facing both forwards and backwards. This 200mm gap allows all the technological components to be mounted within the stand and all cabling can be routed neatly down the vertical pole to avoid trip hazards. A 24" screen is mounted behind a cut-out in the forward facing whiteboard. A cut-out above the screen allows the mounting of two high definition web-cameras, one of which tracks the presence of users by facial recognition and another which can take a snapshot of activity on the table when activated by the user via feedback buttons. A third webcam mounted on top of the whiteboard tracks hand movement over the table surface. The rear whiteboard is removable allowing easy access to the technology for mounting and modification. A colour changing strip of LEDs, mounted behind opal acrylic, runs up either side of the whiteboards and is also linked to the feedback buttons and acts a traffic light system to indicate to the facilitator how the users are progressing with a particular task. (See Fig. 2 in Appendix A)

Separating the table from the stand and keeping it free of wired components allows it to be more flexible in configuration and use, meeting the second UD principle – Flexibility in Use. Because of its D-shape, tables can be fitted together to increase surface area if required. The table and its configuration in relation to the stand is designed to adhere to the first principle of UD - Equitable use. A particular observation during the user research was the position of group dominance that was held by a learner who operated the controlling computer or laptop during technology classes using programmable kits. Usually, this learner was the owner of the laptop in question and was naturally reluctant to relinquish control to another group member, creating a potential for asymmetrical learning within the group. In order to avoid this, the proposed design mounts the screen on which the GUI and feedback visualisation is displayed in a central position above the table surface so that all group members can see the screen and input into screen-based tasks equally and fulfilling the clear line of sight guideline in UD principle seven - Size and space for approach and use.

Posture

In response to the postural user requirement identified above it was decided to design the table work surface height for predominantly standing use. As well as promoting movement during educational activities which is discussed below, the postural and attendant health benefits of standing or perched sitting (as opposed to 90-degree sitting) are well documented (Cardon et al, 2004; Dalton, 2008; Breithecker, 2005) and the basis behind ‘sit to stand’ movements like “Get Britain Standing”. The height adjustment offered by the table means that users can reduce the working height to suit 90 degree or reclined sitting should they require it in line with UD principle two – Flexibility in use.

Movement

Social. Allied to the postural and health benefits of standing mentioned above, there are also social benefits to the mobility which standing offers while engaging in group work. Primarily, it means a greater degree of equality between learners and teachers. In a traditional learning environment, the students sit and the teacher stands creating an automatic hierarchy and position of dominance for the teacher. In a scenario where learners are standing, a teacher approaching the group does so at the same level promoting a greater sense of equality within the classroom.

Educational. Although anecdotal at this stage, feedback from users of prototype furniture during trials which compared low sitting to standing height tables indicated that the

users preferred to stand during hands-on tasks that required the manipulation of physical components. In post-trial interviews, users expressed the opinion that standing allowed them greater mobility and dexterity during the task and also meant they could easily move to a better viewing position when the class facilitator was demonstrating the task on a projector screen.
Key elements of educational group work that PELARS seeks to promote and encourage are engagement, collaboration, sharing (of objects and ideas), discussion, problem solving, brainstorming and storyboarding. While the coding and analysis of video footage from user trials is still ongoing, observations of the same trials would suggest that groups that are standing during a given task are more discursive, collaborative and engaged in the task than their seated classmates.

Ergonomics

The design of a work station with such a wide range of potential users provides a challenge to the ergonomic criteria underpinning the location of the main design elements.
In particular, the height of the work surface is a key element to position correctly as this affects how every potential user interacts with the physical components of the programmable kits.
In adherence with UD principle seven – Size and space for approach and use, height adjustment of the main work surface was deemed essential as this allows the table to be used by a wide range of user heights and in various postures from low sitting to standing. Recognising that for classes of longer than one hour duration, standing may not be comfortable for all users, high sitting or perching is also possible. However, high sitting or standing height is not accessible by a wheelchair user so height adjustment is required for this scenario. The current design has a height adjustment capability of 400mm with a maximum table surface height of 1095mm (1070mm clearance underneath) and a minimum table surface height of 695mm (670mm

clearance underneath). This range of height adjustment allows the table surface to be fixed between the minimum and maximum values of 685mm and 865mm recommended for wheelchair use. The adjustability of surface height also means that the table can accommodate a range of ambulant users from the 5th percentile British 12 year old girl - elbow height 840mm to the 95th percentile British man aged 19-65 - elbow height 1180mm (Pheasant & Haselgrave, 2006).

Reach distance to the centre of the table is another important ergonomic aspect of the table design so that all potential users will be able to fully exploit the table surface and engage with the learning kit and components. The current width and depth of the table is 1100mm. Given that the forward grip reach of the 5th percentile British 12 year old girl is 550mm and 835mm for the 95th percentile British man aged 19-65, the table width and depth allows usage to the centre of the table by the majority of the potential user group (Pheasant & Haselgrave, 2006).

Learning Analytics System: Sensing Technologies

Examining the mainly software based LAS with regard to the principles of UD is beyond the scope of this paper. The discussion below is limited to the UD aspects of the physical elements of the LAS.

In the current iteration of the LAS, sensing technologies consist of three web cameras. The three cameras are used for face recognition, hand motion tracking and capturing snapshots of activity on the table at a given time. This last camera is activated by a user pressing one of two feedback buttons mounted on a free-standing box which is connected to the LAS by Bluetooth. These buttons are used to record the sentiment of the user at the moment of activation. One button (with a lightbulb icon) is intended to be pressed when the user is excited, has a sense of achievement or a "Eureka" moment. The other button (with a lightning cloud icon) denotes frustration, lack of understanding or a problem (See Fig. 3 in Appendix A). The mobile design of the box adheres to UD principle three – Simple and intuitive use, as the usage and graphic icons are consistent with expectation and intuition and do not require understanding of language to operate. Activation of either of the buttons takes a photo of the current activity on the table and records this, along with the relevant button icon, on the visualisation dashboard.

The button activation also provides a visual cue to the facilitator or teacher in the form of a traffic light system. The colour changing LED mentioned above changes to blue when the problem button is pressed and turns to red when the Eureka button is pressed. This method of redundant cuing adheres to UD principle four – Perceptible information and means that the teacher can quickly asses how each group is progressing with a given task by visually scanning the classroom and can then take the required action.

Arduino Talkoo Kits

The Arduino Talkoo Kit consists of a number of 25x25mm printed circuit board (PCB) components, a graphic user interface (GUI) through which the user interacts with the physical components and the logic software required to run the system. Each of the PCB components contains an input or an output element for example a push button, a potentiometer, an LED or an accelerometer (See Fig. 4 in Appendix A). By connecting flexible leads, the user can link the components to each other and to a control hub which is then linked to a computer. The hub recognises each component linked to it and the order of linkage. The user can then activate and control the hardware through the associated software application and GUI (See Fig. 5 in Appendix A). The GUI contains two colour coded tabs which are the main control element for the hardware components. A blue tab activates a toolbar with graphic icons for each of the physical components available in the kit and a brown tab contains an icon for each available logic sequence (such as “if”, “and” or “interval”). By dragging and dropping the icon for each physical component, the user can recreate on screen, the sequence of the connection of physical components they have assembled. Then, by linking tabs on each component icon on screen, the user creates links within the software which instruct it how to control each component in the assembly. Each component icon can be highlighted to activate a dialogue box in which the control parameters of the component can be modified. By connecting icons from the logic sequence toolbar to the physical component icons, conditions for the operation of the assembly components can be added. When the physical assembly is complete and the graphic representation of the assembly is fully linked with parameters set, the user can physically interact with the hardware components (by pushing buttons, moving the accelerometer or changing potentiometer values) or the GUI controls to test and modify the operation of the assembly.

The intention of the kit is to provide a “plug and play” scenario which eliminates complexity, encourages experimentation, creative interaction and provides an introduction to programming and coding. There are many elements of both the hardware and software design that adhere to the UD principles of flexibility in use, simple and intuitive use and provision of perceptible information. Through programmable parameters and modifiable coding, the kit provides layers of complexity which the user can engage with at their proficiency and comfort level and thus control the pace of their own learning adhering to UD principle two – Flexibility in use.

Design Process

The current designs outlined above are the result of an ongoing agile and iterative design process that seeks to continuously test and learn so that the final proposal has gone through several cycles of prototyping, trialing and evaluation before it is released. This process is examined in further detail below.

Trials

A series of prototyping and evaluation cycles were devised within the project structure in order to trial the proposed design in real settings with learners from anticipated user groups. The purpose of these trials is to inform the progressive refinement of the design in an iterative manner taking into account user feedback, observation, video and photographic documentation from the trials sessions. The data generated is analysed to gain insights into how the learners interact with the system and what improvements could be made to the functionality of the furniture and environment with regard to universal design principles and the design intent.

Trials carried out to date include: form and height studio tests with cardboard mock-ups carried out in NCAD, form and height lab test carried out in Citilab, Barcelona, trial of the first complete prototype in the Copenhagen Institute of Interaction Design and the trial of the second generation prototype with the complete LAS system at the Ars Electronica exhibition in Linz, Austria. There are two further series of “in-the-wild” trials planned over the next year of the project to be conducted in each user context which will provide a rich source of user data and feedback to inform further development of the project.

Prototyping

The prototyping process within the project to date has proven invaluable in the ideation, development and testing of the system. Full scale mock-ups and models have allowed aspects of the design such as accessibility, usability, lines of sight, reach distances and usage forces to be tested and evaluated in reality. Prototypes produced have also allowed the objective testing of the system in user trials which in turn generated feedback to input into the next iteration of the design.

Evaluation

The intent of the evaluation process is the objective measurement of the performance of given aspects of the design against specified criteria. At the time of writing, the criteria for the formal evaluation of the furniture and environment and the technological aspects of the project are under development. By setting key performance criteria informed by universal design principles we hope to generate an evaluation matrix which can be completed after each round of trials. Thus, by creating an iterative cycle of prototyping, testing and evaluation any potential problems can be identified and user needs that are not being met can be highlighted. This information will then form the basis for modification to the subsequent prototype which in turn will be evaluated to determine if the modifications carried out were successful or not. Through this cyclical development we hope to achieve a final system design which meets as many user requirements as possible.

Conclusion

Consideration of user requirements at the outset of a design project is fundamental to the formulation of a design brief, direction of the design process and ultimately, the success of the project outcome. In order to meet user requirements and to serve the needs of those users adequately, the principles of UD can be employed to guide the design process to a solution that maximizes the appeal, accessibility and usability of the product, system or service.

This paper has discussed the application of UD principles to aspects of the PELARS project as an example of how UD principles and guidelines can uncover and address aspects of user needs that may otherwise be overlooked in a multifaceted project. By examining the range of criteria that the various learning contexts present to the designers in the areas of furniture and environment, LAS and programmable kits, the benefits of UD as a means of identifying and addressing user needs have been clearly demonstrated. Through the recognition and identification of user needs, the designer is then placed in a position of enriched knowledge and can respond accordingly by providing for those needs. The PELARS project, though currently just past the halfway point, has reaped benefits from the application and usage of the UD principles which will continue to guide the design direction of the project until its conclusion.

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Appendix A: Figures

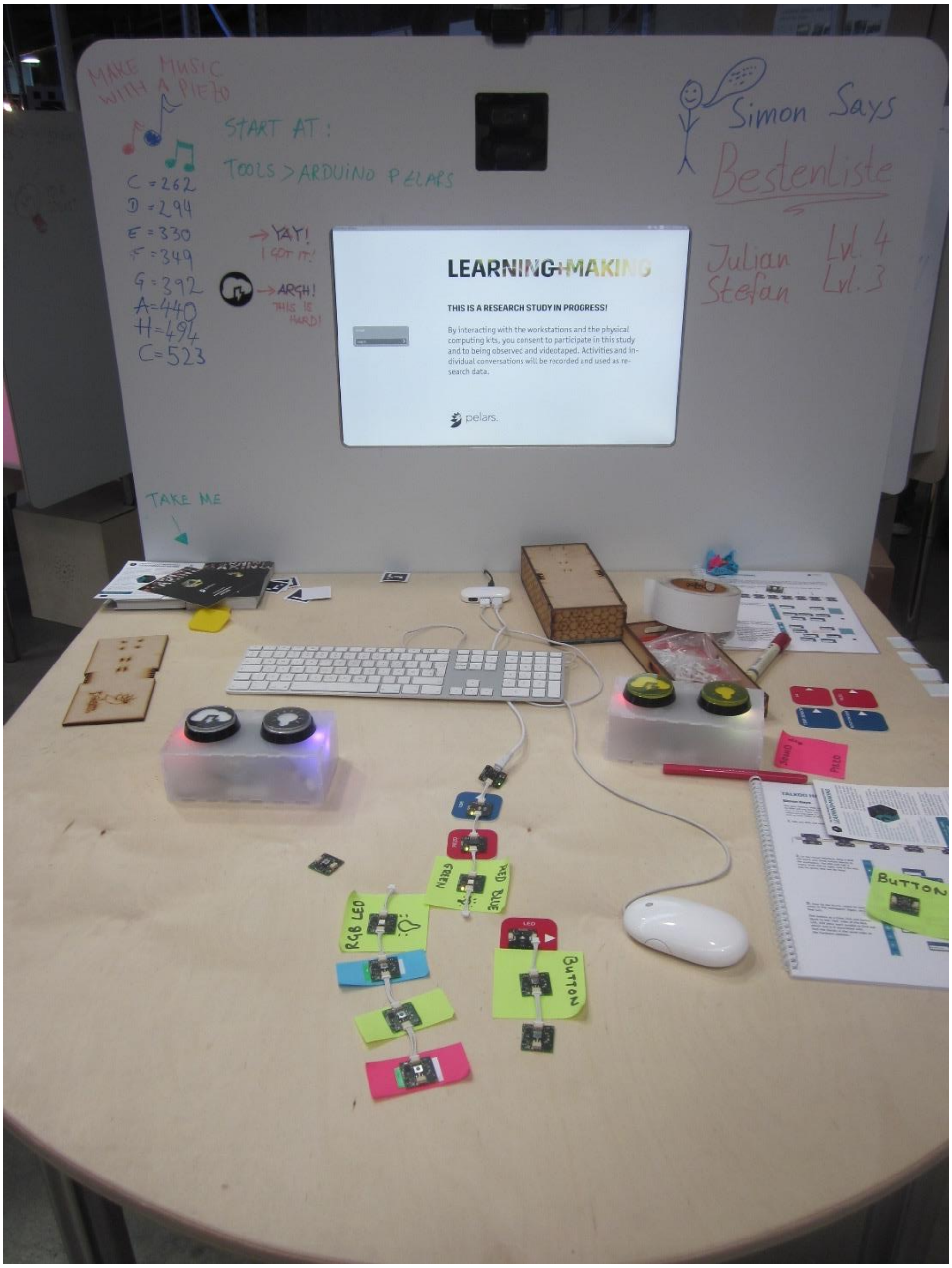

Figure 1. Current configuration of D-shaped table with the stand containing the technology components to the rear.

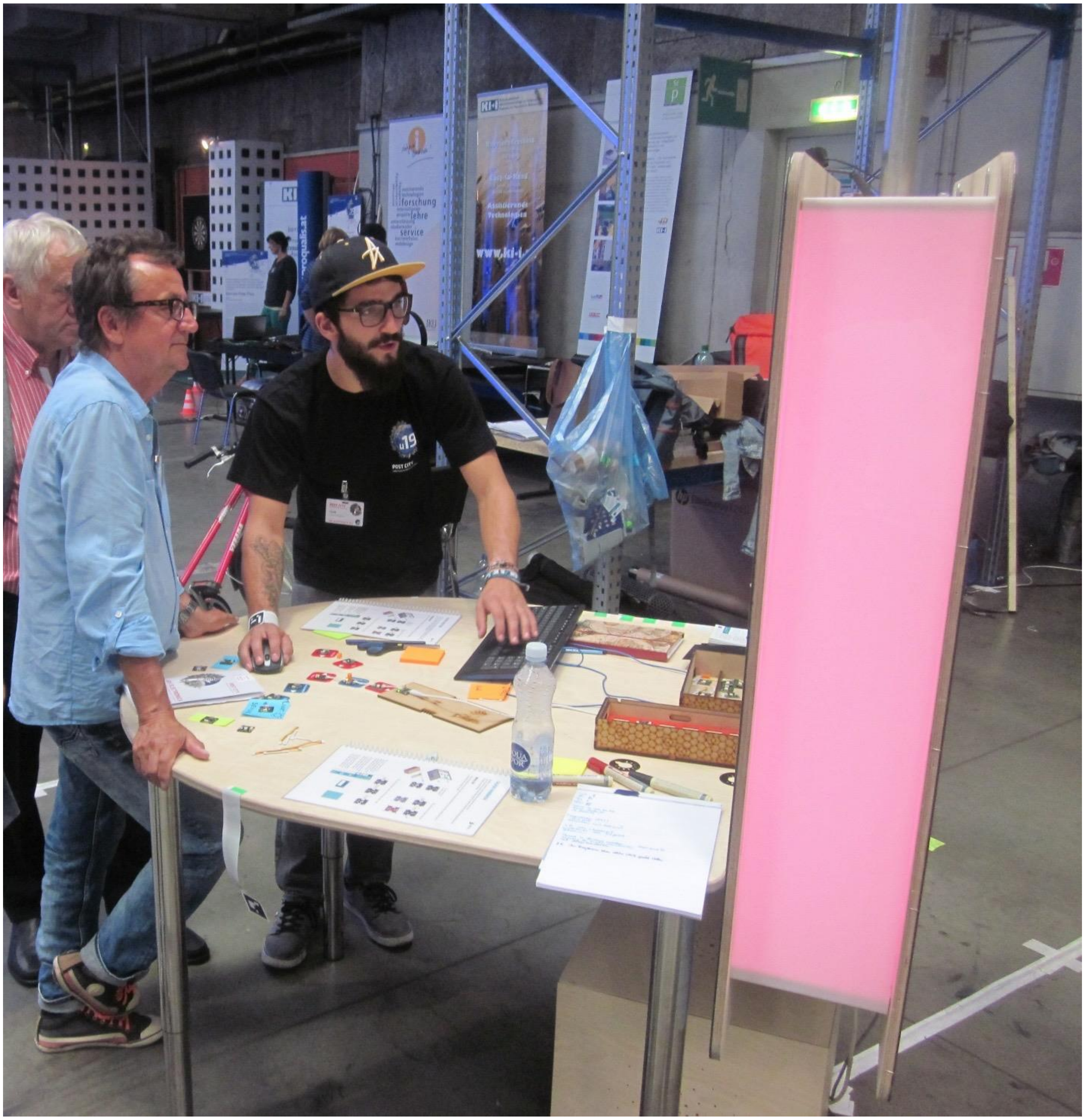

Figure 2. Side view of table showing the colour changing feedback indicator.

Figure 3. Mobile feedback buttons with graphic icons to indicate expression of user sentiment.

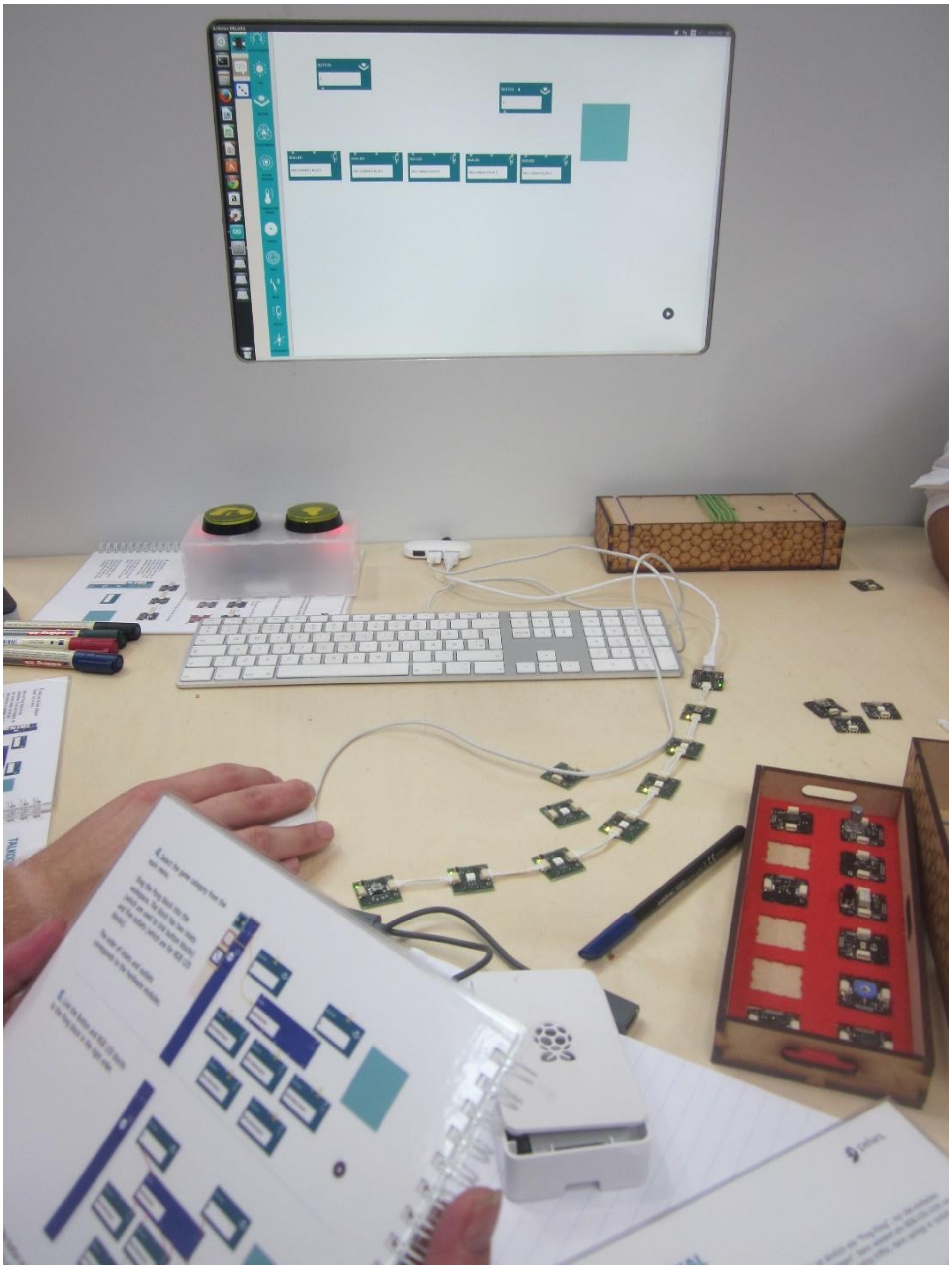

Figure 4. Arduino Talkoo Kit with physical components connected to control hub and represented by the blue blocks on the screen behind.

Figure 5. Arduino Talkoo graphic user interface showing linkages between the physical components (blue) and logic operators (brown).