The ‘Cube’ and the ‘Poppy Flower’: Participatory approaches for designing technology-enhanced learning spaces

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The Cube and the Poppy Flower: Participatory Approaches for Designing Technology-Enhanced Learning Spaces

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This paper presents an alternative method for learning space design that is driven by user input. An exploratory study was undertaken at an English university with the aim of redesigning technology-enhanced learning spaces. Two provocative concepts were presented through participatory design workshops during which students and teachers reflected and discussed the values of technology and provided insight into how to effectively embed technology in learning space design. The findings provide a set of recommendations for integrating technology with learning spaces and present alternative designs for the given concepts.

Introduction

The design of learning spaces in higher education has, until recently, been influenced by traditional paradigms of teaching that originated in ancient Greece and Rome, whereby the lector would proclaim scripture readings to the monks who vigorously copied what they heard, without any form of questioning or interaction. Until the end of the last century this translated into classrooms based on the type of transfer of knowledge where the teacher would recite information from a book while the students listened and copied the lessons into notebooks (Beichner, 2014). Lecture theatres were designed based on this paradigm of transmission of knowledge. As noted by Beichner (2014), the word theatre comes from the Greek the beholding area where patrons sit to view a spectacle.

In recent decades, a new paradigm of learning has been changing practices and roles, suggesting that students be more active in taking responsibility for the ways in which they engage with their learning. This new paradigm suggests that learning should be more active, collaborative, and inquiry-based; it also encourages learning strategies that are enhanced by discussion and practice (Beichner, 2014; Miller-Cochran & Gierdowski, 2013; Park & Choi, 2014; Pederby, 2014). In response to some of these changes, smaller, more flexible spaces have been designed while larger lecture theatres have gradually been transformed to become smaller, more technologically enhanced, and flexible. These smaller spaces are becoming the mainstream of learning space design, informed by the pedagogical discourse of active learning. However, researchers have put forth the idea that the design of learning spaces should aim more at anticipating scenarios and meeting the needs of the students of tomorrow (Williams, 2014; Wilson & Randall, 2012) rather than following the given pedagogical discourse. The more recent thinking suggests that learning space design should be bold and future-proof, encouraging creativity and innovation as well as active learning (JISC - Joint Information Systems Committee, 2006). This research investigates new ways of designing learning spaces that are future-proof and relevant for users. Furthermore, it discusses the purpose and value of technologies in such learning spaces. The method used provides a creative space wherein students and teachers critically reflect on the purpose and value of technologies and co-create new proposals for technology-enhanced learning spaces that are more linked with users' needs and perceptions and less with mainstream pedagogical discourse.

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Theoretical background

Until recently, higher education research has not addressed the issue of the physical spaces in which learning occurs, as the focus has traditionally been on topics that concern pedagogical practices, policy and curriculum design (Temple, 2008). New research concerning learning space design and the impact that such designs may have on both learners' experience and teachers' practices has emerged (Brooks, 2012; Park & Choi, 2014; Scott-webber, 2013). The evidence appears to suggest that learning space design has an influence on how teachers and students interact with the learning process (Beichner, Saul, Allain, Deardorff, & Abbott, 2000; Crook & Mitchell, 2012; Park & Choi, 2014). Jessop et al. (2012) found that learning spaces influence how

teachers perceive their style of teaching, either by encouraging new landscapes of pedagogy or constraining their imagination and creativity. Along similar lines, Brooks (2012) demonstrated that teachers' and students' behaviours changed when comparing a traditional and a technology-enhanced active learning classroom. The research showed that not only were there differences between the pedagogical practices within each type of space but that both students' and teachers' behaviours changed accordingly (Brooks, 2012). In the latter case, the teachers acted more as facilitators by monitoring the students' work and designing strategies for more active and collaborative learning, and as a consequence, the students become more active and participative.

The evidence indicates that there is still much research that is needed in this area, particularly with regard to when and how learning experiences and pedagogical practices can inform the design process (Jamieson, 2003; Könings, Seidel, & Merriënboer, 2014). Simultaneously, the role of technology in learning space design has been widely discussed. Research has shown that although technology may improve learners' experience, it is often approached in an unsophisticated manner, especially when compared with contexts in which learners utilize technology in their day-to-day lives (Baepler, Walker, & Driessen, 2014; Könings et al., 2014). Virtual learning environments can be ascetic and dull, with laptops not fitting on the tables or power outlets being scarce. Interactions with the teacher occur either when students raise their hand or, in some cases, through audience response systems (Terrion & Aceti, 2012). Smartphone and tablet integration in classrooms appears to remain a theoretical construct and, when it is used, usually feels unnatural (Rossing, Miller, Cecil, & Stamper, 2012). Technology seems to be more frequently used to connect with the outside world than to add value to classrooms. Pedagogical approaches appear incoherent and not aligned with the potential of technology, as they seem too formal and sometimes artificial. We agree with Cerratto-Pargman et al. (2012) when they suggest that technology integration must be planned from the beginning and approached on a level that is similar to pedagogy and space, as is shown in the examples below.

Previous experience with the design of technology enhanced learning spaces

The first attempt to bring the benefits of collaborative and interactive learning to larger classrooms using technology was the SCALE-UP (Student-Centered Activities for Large Enrollment Undergraduate Programs) project at North Carolina State University (Beichner, 2014; Beichner et al., 2000). A learning space layout was redesigned focusing on the teacher's position, how the students were seated (cabaret-style), and the integration of three computers on each table with nine students divided into groups of three. The originality of this project is that it combines the redesigned instructional space with the reformed pedagogy that the teacher employed. The students would work together in groups of three to respond to a specific problem. In this project, the space informed the design of a new pedagogy.

A similar study was conducted at the Massachusetts Institute of Technology with the TEAL (Technology Enabled Active Learning) project. TEAL uses media-rich software for simulation and visualisation to physics in a redesigned classroom that facilitated group interaction (Dori & Belcher, 2005). The research found that students interacted socially as they developed their conceptual understanding in a way that was not possible in more traditional space layouts. A similar study at the University of Minnesota (the Active Learning Classrooms - ALC) found that in these technology-enhanced spaces students outperformed other students who participated in traditional classroom environments (Brooks, 2011). Finally, the research reports positive improvements in academic achievement, interactivity, and engagement as a result of students' experiences in using these technology-enhanced active learning spaces (Park & Choi, 2014; Wilson & Randall, 2012). Thus, there is solid evidence that redesigning learning spaces by linking pedagogy and technology is effective (Radcliffe, 2009).

How learning spaces are being designed

There seems to be general agreement within the literature that when designing learning spaces, institutions should take into account students' and teachers' perceptions of inhabiting such spaces (Bligh, 2014; Leijon, 2016; Williams, 2014). One practical example is provided by Lincoln University in the UK. The space planning team facilitated a workshop in 2013 that involved students and teachers. Through the use of design metaphors, a group of fifteen participants identified a set of factors that informed the university's learning space design. The findings were clustered into two groups: (i) spatial factors, which were concerned with the physical environment in general, including the room layout and furniture; and (ii) social factors, which were concerned with the degree to which a room facilitated participation, engagement, and collaboration (Williams, 2014). This research suggests the use of design metaphors as a way to help users critically engage in discussions, as they may need help in understanding "the what" and "the how" in the redesign process as well as in reflecting their perceptions about space design. The suggestion to use design metaphors aims to

involve all participants in the same framework of thought, which can result in more consistent and coherent data.

Still, in relation to Williams's research (2014), we may argue that with students and teachers in the same workshop sessions, the opinions of the teachers may dominate during design sessions, as they may see themselves as being more mature users of the space; hence their voice may suppress students' voices. We therefore argue that both stakeholders must be provided with a safe environment in which to discuss space with their peers. Only after such design sessions have been conducted should the results be analysed and compared.

Brown and Long (2006) suggest three main principles to facilitate learning space design. First, it should be focused on the learning experience and pedagogical theories as well as how students learn individually and in groups. Second, there should be an increase in the ownership of technological devices that enrich learning. Finally, the design process should be influenced by human-centred concerns, hence the need to respond to the integration of the services and devices that support learning rather than merely making them accessible. This is a particularly interesting finding, as technology has sometimes been seen as being tolerated in space design and not necessarily viewed as integral.

Two Australian authors present two similar frameworks to support the design and evaluation of learning spaces that position technology as a necessity; in these frameworks, technology is combined with pedagogy and space characteristics. Both *Pedagogy-Space-Technology* - PST (Radcliffe, 2009) and the *Pedagogy-Space-People-Technology design model* - PaSsPorT (Reushle, 2012) incorporate a flow diagram and a set of questions as tools to promote participants' reflections leading to the development of new ideas and outcomes. These frameworks provide a graphic illustration of the relationships between pedagogy, technology, and space. Reushle (2012), informed by Radcliffe's work, suggests that pedagogy is enabled by space and enlarged by technology, that space encourages pedagogy and embeds technology; and that technology enhances pedagogy and extends space.

However, Bligh (2014) argues that these frameworks guide participants to future-oriented discussions rather than seeking concrete decisions about space design. Although we consider Bligh's argument to be valid, we argue that such frameworks are useful in generating insights into how learning spaces should be designed in the future, as they encourage stakeholders to go beyond current design trends. Additionally, these frameworks may provide useful guidance to help stakeholders reflect on what they see as relevant for learning space design, as they provide solid guidance for those who might feel unprepared or who do not have the experience or expertise to discuss space design.

One interesting approach to involving stakeholders in the design process is participatory design. This approach was developed in Scandinavia with the objective of giving stakeholders and consumers the opportunity to actively participate in the design process rather than solely providing feedback after the product is built (Schuler & Namioka, 1993). Participatory design was initially used to aggregate workers' views in the improvement of technology and machinery and their use in the workplace. Although participatory design was initially created in an industrial, socio-political context to involve workers' views and to make them part of design solutions, its use has been extended to many other user populations that include children (Druin, 1999; Frauenberger, Good, & Keay-Bright, 2011) and older adults (Frohlich, Lim, & Ahmed, 2014; Vines et al., 2012). The findings have shown that by involving end-users and/or stakeholders in product design the spaces will become more usable, scalable, and sustainable (Fishman, 2013).

An experience of using participatory design in the higher education field is provided by Craft (2013). Craft used this design approach to solve problems with regard to technology-enhanced learning design, including the design of new software and re-engineering existing technology-enhanced learning systems. Craft (2013) introduces Sketch-in, an activity that leverages the value of freehand sketching for creativity, collaboration, and problem solving. He advocates that this approach supports individual re-interpretive cycles of generating ideas and enhances access to new ideas for individuals and groups.

The benefits of using participatory design in the design of learning spaces are also addressed by Sherringham and Stewart (2011), who suggest engaging end-users to help in the development of design briefs, documents developed by a designer or a designer team in consultation with the clients or stakeholders that sets an outline of the deliverables and scope of the project, as this provides an opportunity to gather a rich collection of associations and embodied experiences related to learning spaces that are helpful to architects and designers. The authors remind us of the incongruences that students find between learning spaces and how they should learn in their disciplines (Sherringham & Stewart, 2011), as they often are not involved in the design process. By using participatory design, designers listen to students and teachers talk about their teaching and learning experiences, which allows them to be more immersed in the experience of producing a meaningful concept and thus gives them a sense of belonging and participation. Furthermore, through the development of playful and visual stimuli, the participants are provided with a channel for open-ended exploration of innovative design solutions (Craft, 2013; Sherringham & Stewart, 2011).

An example of using participatory design in educational spaces is presented by Woolner (2009). The author gives an example of involving a school community in the design of a school. The findings show a significant impact of the initiative and a high level of satisfaction for both the school community and the architects. It also suggests a possible new pathway for engaging different stakeholders in education to work together to improve the quality of education and its different dimensions. Transposing Woolner's (2009) experience to higher education, we believe that participatory design as a method for designing learning spaces can be productively aligned with the ongoing discourse in terms of students' engagement and participation in re-shaping universities and campuses (Neary & Saunders, 2011).

Research design

As we have shown above, participatory design has mostly been used as an approach in the design of learning spaces with the involvement of users. For this research, we also used this approach as a research methodology to collect perceptions about the design of technology-enhanced learning spaces (Spinuzzi, 2005). Participatory design as a research methodology may combine a set of principles from different methods of data collection, such as observations, surveys, informal interviews, and focus groups all the while being strongly rooted in action research methodology (Glesne, 2016). For this research, we used sandpits (Frohlich et al., 2014), which are creative, design-driven focus groups in which, stimulated by a narrative and design themes, the participants are encouraged to redesign proposed concepts as a way to provide rich collection of data to inform future design briefs.

The research took place in a medium-to-large university located in the South-East of England between late 2014 and early 2016. A purposive sample of students and teachers was chosen. Twenty-five students aged 19 to 35, across different disciplines, twelve men and thirteen women, agreed to participate in the study. Thirty-two teachers, also across several disciplines, agreed to participate in the study. Of these, 15 were men and 17 were women, at different stages of their careers.

Thirteen sandpits were conducted with the intent to redesign one provocative concept, either for a large group teaching scenario (nine sandpits) or for a small group teaching scenario (four sandpits). Since we were conscious that teachers' voices could supress students' voices during the discussions, the sandpits were organised for either students or teachers. Each sandpit lasted no more than an hour and was divided into four phases:

I. In the first phase, we presented the research and data collection procedures, which usually lasted approximately five minutes.

II. To illustrate how the provocative concept was designed and how a session would occur in such a space, a storytelling technique was used (Muller & Druin, 2003). Storytelling enables researchers to create a real-life scenario that can bring a sense of authenticity to the provocative concepts. This can provide participants not only the opportunity to reflect on the design themes but also to reflect on how they might engage with the space in a real-life scenario. This has been proven to be effective, as it allows less experienced designers to make common-sense design choices (Boys, 2011). For example, when conducting the sandpit of the Cube, the narrative was based on the experience of lecturing in the Cube narrated by John Lock, a professor in archaeology at Bloom's University, whilst for the students, we used the character of an archaeology student at the same university. While reading the examples, the narrator presented images of the Cube and provided details of how students or teachers would interact with the space (Figure 1). This usually took approximately fifteen minutes.

III. In the third phase, each group discussed and reflected on the presentation of each concept. The participants were given fifteen minutes to discuss the provocative concept and write down what they would like to keep, lose, or change. This strategy, which was also used by Frohlich et al. (2014), provided each group with the opportunity to discuss the features of the space by focusing on what they liked or what they disliked and to discuss the rationale of their decisions. This allowed them to focus the discussions on particular aspects of the learning space. The participants were provided with A3-sized sheets of paper and sticky notes on which to express their thoughts.

IV. In the fourth phase, the participants redesigned the two provocative concepts using sketches, according to what had emerged from the discussions. As discussed by Craft (2013), sketching leverages the value of creativity, collaboration, and problem solving. At each design table, the participants had at their disposal thirty photos of design furniture and technology solutions, which were aimed at providing new frames-of-thinking for those who may have felt unprepared. Scissors, sticky tape, coloured pencils, markers, and a flipchart were available, as the idea was to replicate a design environment. This activity lasted until the end of the session, culminating with each group giving a different name to the provocative concept, which represented how they saw the space following the re-design process.

The data from the sandpits were collected by the researchers using the individual sticky notes, sketches that were made by participants, field notes that were taken by the researchers, and audio recordings. Each sandpit was audio recorded to allow a better contextualisation of each design decision. All of the data were anonymised, the recordings were transferred to NVivo qualitative data analysis Software (from QSR International Pty Ltd. Version 10, 2014), and analysed using a thematic approach (Boyatzis, 1998; Fereday & Muir-Cochrane, 2006).

The data were categorised based on the themes that emerged during the data analyses. For this paper, we will present the findings that are related to the themes of visualisation, tangible user interfaces and interaction with the lecture. A professional designer and co-author later improved the sketches that were drawn during the sandpits so that different details and relevant decisions were explicitly visualised in each final sketch.

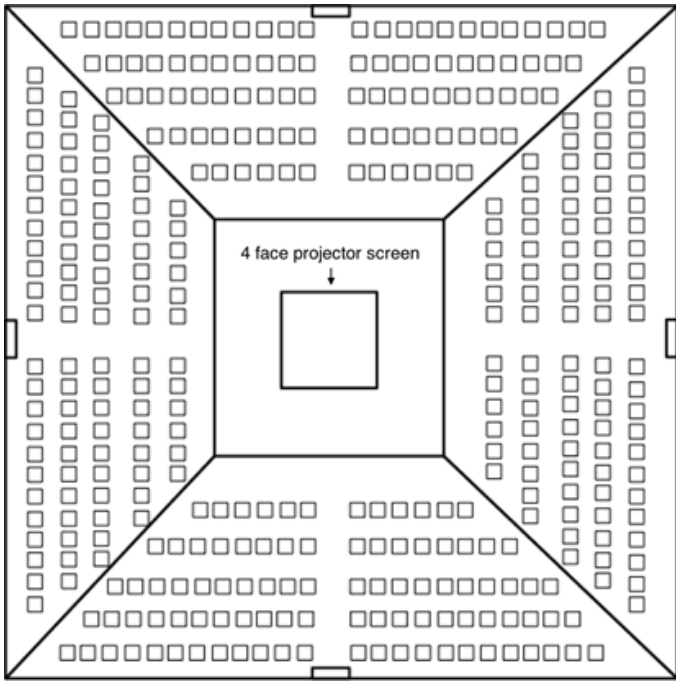

***Figure 1*. Footprint of the Cube**

The design of the two provocative concepts

The Cube concept (Figure 1) illustrates a large lecture theatre with 376 seats wherein the lecturer would be seated in the middle and the students would surround the lecturer. The Cube was designed to enhance interactivity and engagement and allow the students to interact with the lecture using a seven-inch institutionally provided tablet device that was embedded in the students' table. The lecturer would not have a conventional podium but a table top touch screen, which would be used to monitor the students' tablets and projector screens and to manage the room ambience (temperature, sound, light and windows could be changed using the touch screen). The room would have four large projector screens on top of the box. These projectors would face each of the four stands. In the Cube narrative there was an implicit message that the lecturer was in control of the room.

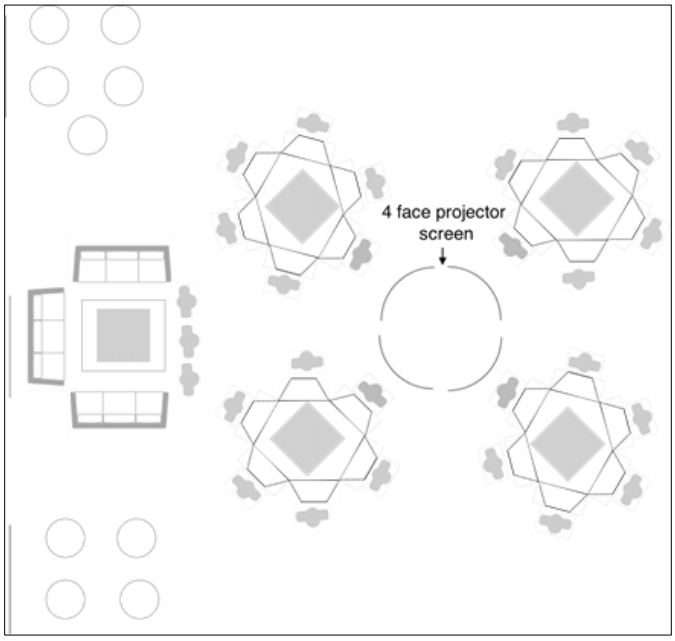

***Figure 2*. Footprint of the Poppy Flower**

The Poppy Flower concept (Figure 2) illustrates a small technology-enhanced collaborative space. The room has twenty-four seats, although only twenty are designated for students, at each table there is one seat dedicated to the teacher. The room is designed to encourage group work and the use of tangible technologies. Each table has one large table-top touch screen, which enables students to work in groups and to share what they are doing with one of the four circular-projector screens that are located in the middle of the room. The teacher, with a 10-inch tablet, controls the projector screens. At each individual seat, the students have their own power outlet, which can be used to plug in personal mobile devices and laptops. A Bluetooth connection can be used to ensure communication between personal devices and the table-top touch screen. There is also a breakout area, with beanbags and sofas, where students may sit and have more informal discussions. The Poppy Flower aimed to lead participants to imagine a student-centred room.

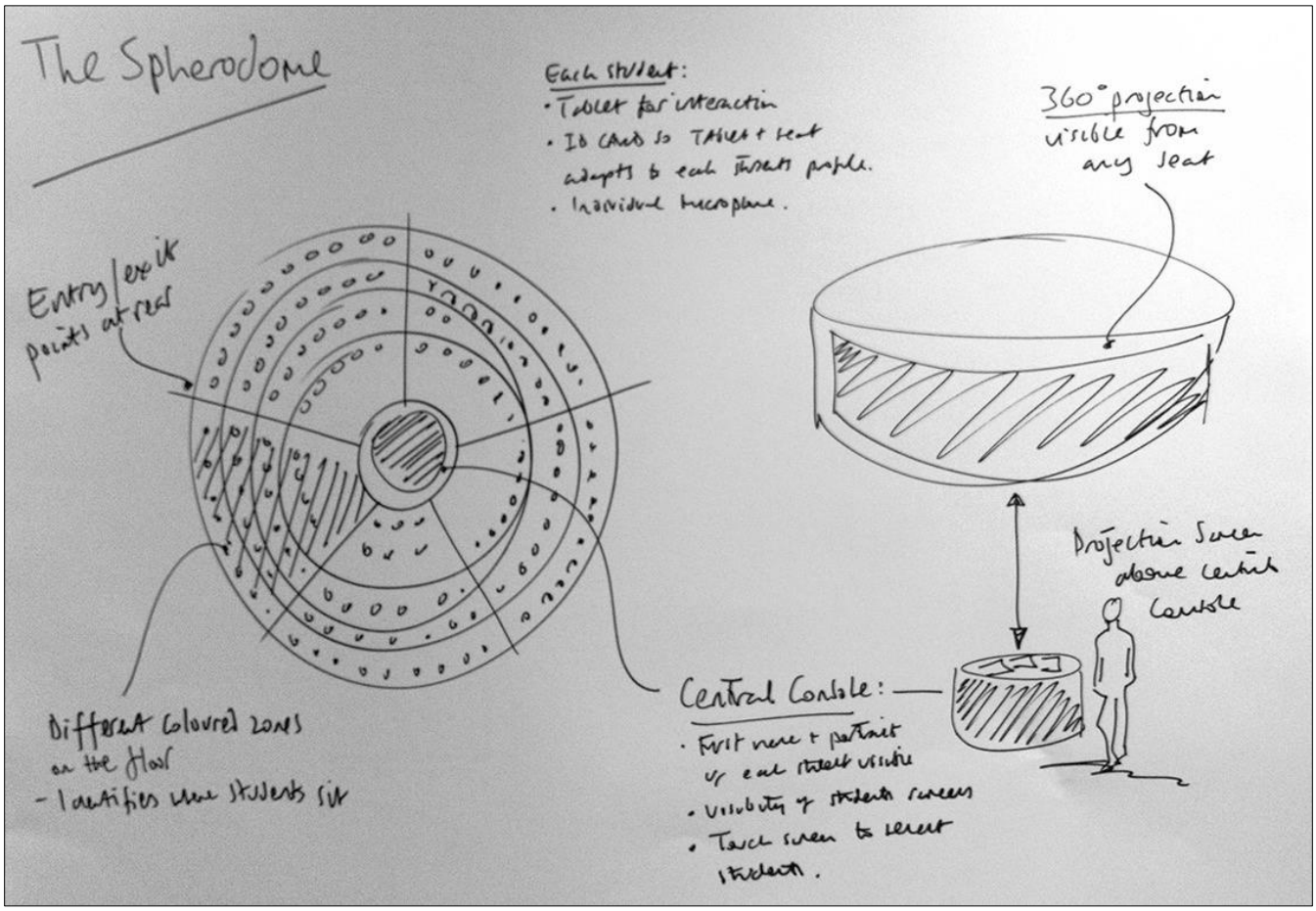

***Figure 3*. The Spheredome, an output of one sandpit with teachers aiming to redesign the Cube**

Findings and recommendations

Visualisation

Visualisation is becoming an integral part of learning spaces design, as it provides an alternative to the traditional communication channel of speaking and listening. The use of MS PowerPoint™ slides or similar presentation software is almost inevitable, and there is a common sense from both students and teachers that a lecture in a higher education setting is not effective without the support of a visual presentation of some sort (James, Burke, & Hutchins, 2006).

In the design process of the provocative learning spaces, we placed projector screens in the middle of the room (Figures 1 and 2) although they had different shapes (square and curved formats). The novelty of the projector screen formats and locations was a topic for discussion, as they were considered to be a valuable add-on for traditional classrooms. There was a sense within the groups that the existing solutions do not foster learning, as they are usually *small*, the image has *poor quality*, it is *affected by external light* and *difficult to read from a long range*. The general feedback from the sandpits revealed that the size of projector screens was an important factor and that the quality of the projected images and sound when listening to multimedia files might influence students' engagement. The use of projector screens that were placed higher up was praised, as this would enable everyone in the room to have a similar visualisation experience. Suggestions were made that more screens fixed on the walls would ensure that everyone would have the best possible experience, as this would respond to a lack of visibility caused either by the brightness of the sun or by the angle of the screen. This solution has been explored in terms of different learning spaces, especially in computer labs or technology-enabled rooms (Beichner et al., 2000). Few comments were provided about combining different visual outputs at the same time in the wider projected screens as suggested in the Poppy Flower narrative. Both stakeholders' groups shared concerns that combining different visual stimuli at the same time would confuse students as they would not know which image to follow, and it would disrupt the teaching and learning process.

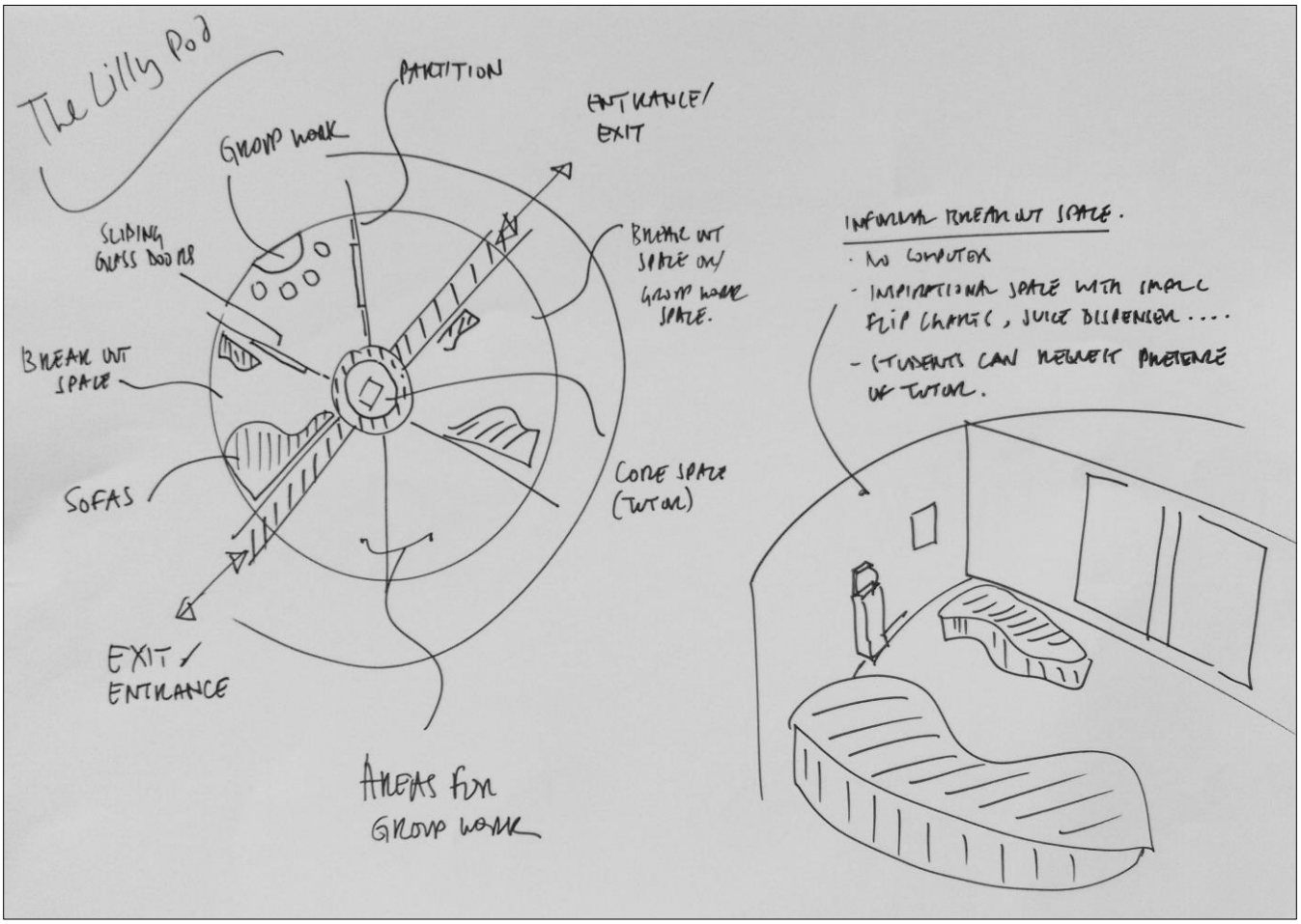

Figure 4. **The Lilly Pod, an output of one sandpit with students aiming to redesign the Poppy Flower**

When given the opportunity to redesign the visualisation elements, the participants preferred spaces with curved shapes or curved-shaped equipment, suggesting that it might provide a sense of *openness and to be more inspirational* (teachers' group one). This is particularly relevant as the current trend for learning space design suggests more linear lines, as they provide a more effective organisation of space.

Figures 3, 4, and 5 present the redesign of the Cube and the Poppy Flower that included both curved shape rooms and curved design elements. In Figure 3, the projector screen and the central console would have a cylindrical shape, which would enable the projection of images in a more immersive way.

In the Lilly Pod proposal (Figure 4) – a redesign of the Poppy Flower - the students face the wall in smaller dedicated rooms, where a curved shape screen will project the images on which they are working. In these redesigns, it is possible to see alternative designs with a curved shape for the screen and walls where images would be projected. The participants justified this solution by arguing that it would provide a greater sense of depth, which would foster more engagement and interactivity.

Recommendation 1: Our first recommendation is that when designing technology-enabled learning spaces, we should provide more projector screens with different configurations, combining traditional projections with alternative ones, such as using different walls or using smaller monitors. An example of a similar approach is presented in the SCALE-UP (Beichner et al., 2000) or in the TEAL (Breslow, 2010) space configurations. Other possible scenarios are to explore the use of embedded tablets or large monitors for each group table, which would enable connection with personal devices (see in Figure 5 the different screen configurations proposed).

In this Tulip proposal (Figure 5), there is a learning pod where students would work as groups using their tablets, and the image would be projected through a Bluetooth connection to the pod wall. Multiple screens on the wall would project each group's work and provide an alternative view to the other students and the teacher.

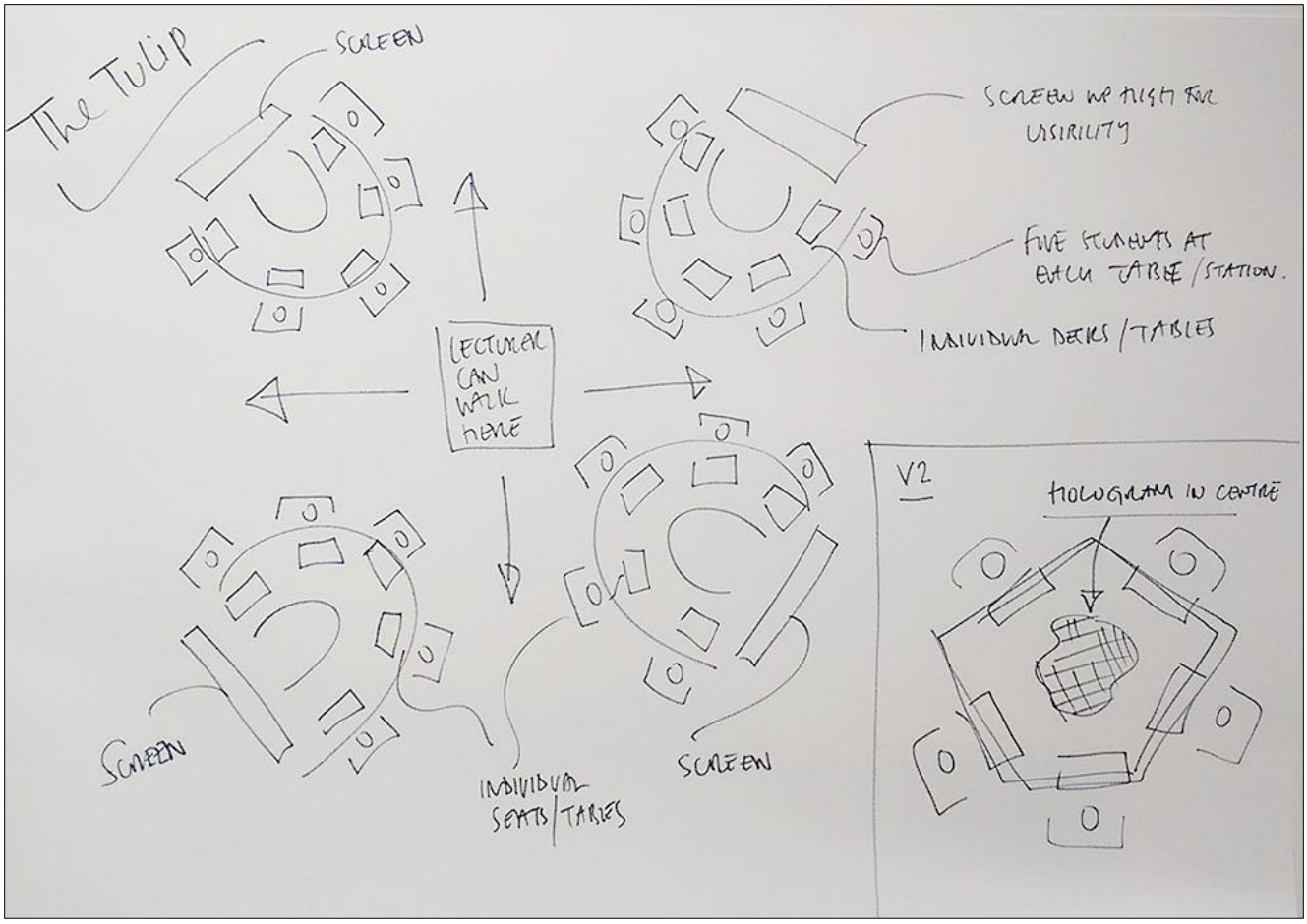

Figure 4. **The Tulip, an output of one sandpit with teachers aiming to redesign the Poppy Flower**

Recommendation 2: Our second recommendation is to provide the opportunity to project images with a curve-shaped display either by designing the room walls without straight lines to ensure immersive projection or designing the projector screen display with a curved shape. The findings suggest that the visualisation of information would have a sense of *openness and to be more inspirational*. These findings are supported by the research that has evaluated user satisfaction and the effectiveness of large curved screens compared with large flat screens (Andrews, Endert, Yost, & North, 2011; Shupp, Andrews, Dickey-Kurdziolek, Yost, & North, 2009).

Tangible user interfaces

The use of tablets and tangible user interfaces in higher education has been a recent topic of research, specifically with an increased interest from the learning technology community (Dillenbourg & Evans, 2011; Rossing et al., 2012). The research has concluded that although this technology is being seen as having value for learning and teaching, there is still room to develop more meaningful pedagogical resources and activities that match the potential of the technology (Rossing et al., 2012).

From the sandpits, we found that the students were positively impressed by the role of the tablets in the two learning spaces concepts. The possibility of being able to interact with the projector screen was highly motivating, as it would give them an opportunity to interact with the lecture and thus play a more participative role. It should be noted that concerns were raised about the need for simplicity of access and the use of tangible user interfaces so that the setup could be as seamless as using a notepad.

During the students' sandpits, a large number of references were made to the ownership of mobile devices. The feeling was that for formal learning, institutional tablets should be utilised rather than personal smartphones or tablets. The rationale used by the students was that they would not like to amalgamate their family and friends' interactions with readings, discussions forums, or tutors' e-

mails. In their opinion, the two worlds needed to be separate, and the use of a customisable institutional tablet would provide a solution to overcome this. They added that all the devices should have a degree of personalisation, which would enable them to have their own learning environment. Two of the students groups stated that they would lose the power outlets at every seat. According to these students, by having power outlets, the learning space provides a message that they are encouraged to use their own mobile device in the classroom. They discussed that the use of personal devices would distract students because of the *outside noise* from friends or family.

Contrary to the students' perceptions, the teachers' groups suggested that students would prefer to use their own mobile devices, as they are more familiar with them. One group (teachers' group two) said that the students would prefer to use a traditional notepad for writing, as the tablets would take up desk space. Moreover, concerns were raised that the use of tablets to interact with the lecture would detract from the traditional question and answer method of teaching, as the students would be too focused on the tablet rather than taking advantage of the physical environment. There was a sense in this group that an excessive use of technology would jeopardise the traditional teaching and the exchange of opinions and views. Conversely, one group of students and one group of teachers said that the use of tablets could be a perfect solution for the students to write in their notebooks whilst they visualised the lecture on their tablet, an approach that both of these groups favoured.

The findings provided interesting insights into the role of personal devices in learning spaces, as there was clearly a mismatch between the students' and the teachers' perceptions. The literature provides contrasting opinions about the ownership of tangible user interfaces. Although there appears to be a trend to bring your own device for learning with arguments that are similar to those that were stated by the teachers in this study, several other studies refer to particular challenges around privacy, equity, technical support, network security and quality, and even possible classroom disruption (Grussendorf, 2013; Santos, 2013). The latter is also supported by the findings that were collected during the sandpits, as the teachers were concerned about an excessive use of technology.

Recommendation 3: Our third recommendation is the use of institutional customisable tablets as a tool to promote more interactive learning in classrooms, since they are seen by students as being simple, usable devices. We suggest institutional tablets to be used as a tool to bridge the gap between the face-to-face environment and the online environment. However, we recommend these tablets to be institutionally supported, as this would provide more equal opportunities, a more usable and consistent interface, as well as a better and safer internet connection. However, these tablets should be customisable to the student experience yet only be related to their formal relationship with the university.

Interaction with the lecture

Both provocative concepts were designed to provide a strong message - that by using technology, both tablets and table-top touch screens, the learning spaces would enhance interaction with the lecturer. Suggestions were made throughout the storytelling phase to use tangible technologies to support electronic voting, a twitter-chat channel, and to allow for the projection of the on-going work in each group from the table-top touch screen to the projector screens (the Poppy Flower in Figure 2). These scenarios were highly appreciated, as they would allow an easy interaction between students and the lecturer. There was a sense within the groups that a technology-enabled learning space should foster seamless access to information and that an intelligent dashboard in the individual tablets would be a good solution. By congregating all the features into just one tablet, the students would focus their attention on only one input or output channel and be more focused on their learning. There was also a suggestion that the tablets should foster dialogical communication between the students and the lecturers through bidirectional communication fluxes. Nevertheless, suggestions were made by both the students and the teachers that the use of an embedded tablet would not replace taking notes on paper.

Recommendation 4: Our fourth recommendation is an increase in opportunities for bidirectional interaction with the lecturer and the main projected screens or walls through the use of tablets or similar tangible technologies. At a time when participatory and student-centred learning is being encouraged, learning space design should promote more democratic access to the projection of content.

Final considerations

A participatory design approach provides engaging and creative sessions where active users have space to critique and redesign the concepts that they address on a daily basis. As a methodology that guided this research, it created a space for the production of rich and valuable data that are related to users' perceptions of learning spaces and the value of technology in its design. In this research, we aimed to redesign two provocative concepts of technology-enhanced learning spaces by creating an environment where teachers and students could safely discuss and create their own vision of a learning space. The findings suggest that, although they began at the same point, the collective effort of the participants influenced the final output through their

individual conceptions. These individual conceptions were informed by the participants' personal experiences of learning and teaching in similar spaces (Sherringham & Stewart, 2011).

Interaction and engagement were two areas that were highly referenced during the sandpit discussions. The findings suggest that technology could be a strong ally in promoting more interaction and engagement in learning and teaching. In this regard, tablets were seen as an important resource to promote more engagement and interaction. Furthermore, suggestions were made that the students would enjoy having institutional devices available to help them to engage with the lecturer and to link the face-to-face environment with the online environment.

In terms of the visualisation of content, the findings suggest that curved-shaped screens and a curved projection are recommended as they promote a more immersive environment. However, attention was especially given to access as well as to the quality and size of the image. Also allusions were made to the number of screens that are available in learning spaces, which should be extended throughout the room to promote better access to the projected image.

We present as an output of this research recommendations with regards to the visualisation, interaction and the use of technologies in learning space design. We believe that these findings may inform a design of technology-enhanced learning spaces that can respond to both societal and technological developments.

In this paper, we presented evidence that participatory design is an effective research method to anticipate the learning and teaching spaces of the next decade. We believe that by promoting this form of grass-roots engagement, universities will be able to construct more innovative and meaningful learning spaces. Furthermore, the findings provide valuable insight into practices that will lead to more sustainable and future-proof learning space design.

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