CREATION OF A NEW LEARNING SPACE FOR ANU ENGINEERING

ENGN2225 Individual Portfolio

A design task to re-evaluate the current ground floor computer labs in ANU Engineering and explore new conceptual designs to create a new learning space

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Abstract:

This paper explores the creation of a new learning space in the ANU Engineering Building to better fulfil client needs for a learning space that reflects on the College of Engineering and Computer Science's commitment to collaborative learning. Design criteria were established and a need for change was determined upon evaluation of the current computer labs against customer requirements. A systems approach was used to analyse the system and to determine subsystems, which were then explored using concept generation. A potential design was generated for the three rooms in question and next steps, including contacting suppliers and maintenance personnel, were explored.

Background

The College of Engineering and Computer Science (CECS) at the Australian National University (ANU) serves to recruit and nurture students and academics into world-class problem solvers. As such, one of their primary commitments is to provide "students with the best education and research training experience…(and a) broad knowledge and understanding of other disciplines, communication and leadership skills" (CECS, 2015). However, the client, CECS, feels that the current physical image of the ANU Engineering Building does not reflect this commitment to a world-class educational experience. More specifically, the client wants to repurpose the three ground floor computer labs (see Figure 1) into general purpose collaborative learning environments.

Figure 1 ANU Engineering Building Ground Floor Computer Lab Room E142 (Source: LostonCampus)

The primary motivation for the client's desire to repurpose the computer labs is two-fold. Firstly, the location of the labs as the first rooms accessible from the engineering building foyer means that they play a significant role in determining first impressions of the engineering building and hence CECS as a whole. Secondly, the client believes that the computer labs do not give the impression of collaborative knowledge-sharing and problem solving that CECS aspires to achieve.

However, such repurposing would be an expensive exercise, making it worthwhile to first assess whether a change is necessary to achieve the client aims. This required us to first establish and analyse the client's requirements, which were outlined over the course of multiple meetings with a representative of the CECS committee involved in refurbishing the engineering building (Kanes, 2015).

Client Requirements

Firstly, the client requirements were broken down into more quantifiable technical performance measures (TPMs) in order to make progress towards client needs easier to measure (Gibson et al., 2007). The client design requirements and their corresponding TPMs are shown below.

Table 1 Client Requirement 1 - Be visually attractive

Design Attribute	Metric	Direction
Lighting	Lux	Towards 320 Lux
Colours used	#	↑ to maximum of 6

The requirement for the space to be visually attractive was quite ambiguous. However, it was distilled into the attributes of lighting and room colour. This is because they are relatively low-cost alterations compared to options compared to room reconstruction and furniture overhaul, while still significantly affecting room appearance and being associated with learning factors such as attention and memory retention (Dzulkifli & Mustafar, 2013) (Victoria DEECD, 2011). The target value of 320 Lux for lighting was based on lighting suitable for typical office tasks (Sustainability Victoria, 2010) while the ideal number of colours used was based on research suggesting that using over 6 colours in a learning environment excessively strains cognitive abilities (Daggett et al., 2008).

Table 2 Client Requirement 2 - Easy to get into (human and equipment)

Design Attribute	**Metric**	**Direction**
Size of entrance (Length and Height, not just area)	Metres (L), Metres (H)	↑
Number of entrances	#	↑
Automation	#	↑

This client requirement regarding accessibility for both human users and equipment brought in from outside the learning space was simply distilled into the three most significant accessibility attributes. Increasing entrance size allows larger equipment to be brought into the space, while more entrances can cope with higher user traffic. Automated entrances improve disabled access like wheelchair access, and accessibility of large external items (e.g. for presentations).

Table 3 Client Requirement 3 - Easy to use externally supplied equipment

Design Attribute	**Metric**	**Direction**
Power point to space ratio	Power points per m^2 floor space	↑
Projector to space ratio	Projectors per room	↑
Wi-Fi availability	Signal-to-noise ratio (SNR)	↑

This requirement related to the space's ability to cater for external equipment temporarily brought into the space, such as laptops or presentation equipment. To this end, it was decided that power supplies were essential to cater to the convenient use of external electronic devices. Projectors were also defined as an attribute due to their importance in allowing devices to project to a larger audience. Wi-Fi was also deemed a key attribute for external equipment due to its modern-day importance in receiving and disseminating information.

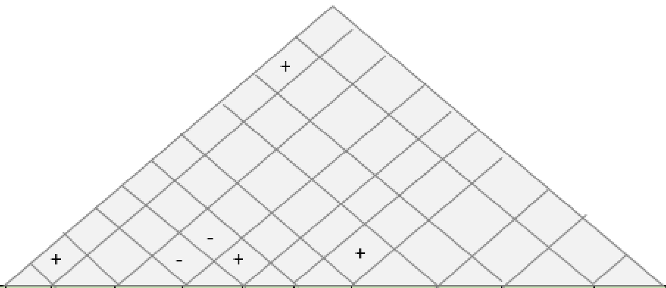
Table 4 Client Requirement 4 - Encourage collaboration between users

Design Attribute	**Metric**	**Direction**
Number of sightlines	#	↑
Furniture mobility	User rating	↑

This requirement was related to ensuring the space is conducive to collaborative work. This requirement was broken down into attributes of how well users could see each other and how easily the furniture (and hence the space) could be changed to allow different sized groups to work together, catering to a wider range of collaborative settings. Sightlines, or unobstructed lines-of-sight, have been shown to be important to encourage collaborative learning by increasing face-to-face engagement (Blackmore et al., 2011).

Having established the attributes and TPMs for each client requirement, it is now important to analyse these for their relative importance to the system. This is due to the necessity for trade-offs, whereby improving some attributes may de-optimise others. For instance, the accessibility attributes of entrance size and number entrances both have a desired direction of being increased. However, increasing entrance size would necessarily decrease the number of entrances that could be fit into the same area of wall and vice versa. In order to ensure these trade-offs are made in a manner that best fulfils client requirements, a House of Quality (HoQ) was used to analyse requirements.

Legend	
Symbol	**Meaning**
Relationship	
9	Strong
3	Moderate
1	Weak
X	Unrelated
Correlation	
+	Positive
(Blank)	No correlation
-	Negative
Direction	
↑	Maximise value
O (target value)	Achieve (target value)
↓	Minimise value



			Column	1	2	3	4	5	6	7	8	9	10
			Direction of Improvement	↑	↑	↑	↑	↑	↑	↑	↑	O (320Lux)	↑ to max of 6
Row	**Customer Importance**	**Maximum Relationship**	Design Attributes / Design Requirements	Number of sightlines	Furniture mobility	Size of entrance	Number of entrances	Number of automated entrances	Power point to space ratio	Projector to space ratio	Wi-Fi availability	Lighting	Colours used
1	1	9	Encourage collaboration between users	9	9	X	X	X	1	1	1	1	X
2	2	9	Easy to access	X	3	9	9	9	X	X	X	3	X
3	3	9	Easy to use externally supplied equipment	X	3	3	X	3	9	9	9	X	X
4	4	9	Be visually attractive	X	3	1	X	X	X	1	X	9	9
			TPM	#	User rating	Metres	#	#	Ppt per m^2 floor space	Projectors per room	Signal-to-noise ratio (SNR)	Lux	#

Figure 2 House of Quality for Learning Space Design Attributes

From the HoQ it can be seen that the design attribute for furniture mobility has at least a moderate relationship with every requirement, while lighting and entrance size are the second most relevant design attributes. These relationships will become more important when trade-offs need to be made, such as during Concept Generation. For instance, taking the previous example of entrance size versus entrance number, we see that entrance size impacts three requirements (accessibility, ease of using external equipment and, to a lower extent, visual appearance due to a larger entrance gives a more open feeling and increasing visibility from outside into the space) while the number of entrances only affects accessibility. This means that entrance size takes prominence over the number of entrances, and as the HoQ shows, the number of automated entrances is also more important than the number of entrances due to the extra functionality of automated entrances.

Evaluation of the Current System

Having established the client requirements and distilled them into design attributes, it is now possible to evaluate the current engineering computer labs against these requirements.

Table 5 Evaluation of current computer labs against CECS client requirements

Design Requirement	**Design Attribute**	**Current System Comments**
Encourage collaboration between users	**Number of sightlines**	Very few sightlines in current room configurations. Currently two main sightlines for E101 and E142 and one for E141, corresponding to region between each row of computers. The desks in rows combined with computers on each desk create very high vision obstruction, decreasing sightlines. Also, the room is geared towards students being seated facing a screen, meaning there is minimal sight in front of the student (a screen). Also, the long rows make it difficult to collaborate as students need to awkwardly rotate to face those behind them and need to find a corner table if more than two people want to work together in order to allow all members to communicate without constantly turning around to face one another.
	Furniture mobility	Very low furniture mobility for computer lab configuration. Desks are very long, meaning they are heavy and occupy a large area. This makes it highly impractical to rearrange the room and also is not conducive to group work as long rectangular desks prevent groups from facing one another in a close arrangement. Also, the desks are restricted by computer fixtures that are connected by numerous wires (held down for theft prevention purposes) further reducing mobility. The only high mobility furniture at the moment are the chairs, which have wheels and can swivel, making them quite mobile and conducive to group work as students can move to each other conveniently.
Easy to access	**Size of entrance**	The current size entrance is 200cm high by 90cm wide. This complies with Australian standards for minimum width of 0.85m (APH, 2015) and so is sufficient for most human access including wheelchairs. However, the entrance size is not well-suited to wheeling in temporary presentation equipment and displays such as air conditioning units stored in labs. Finally, the entrance is also not large enough to allow more than one person through at any one time, meaning only one person can enter or exit at a time, making traffic flow inefficient.
	Number of entrances	There is currently only one entrance per room, and increasing this would improve traffic flow. However, if entrance size is increased then there will be less need to increase the number of entrances. Nonetheless, adding more entrances would increase the maximum traffic capacity that could flow through into and out of the system.
	Number of automated entrances	There are no automated entrances at present, making access difficult for disabled persons. Having at least one automate entrance to each room would greatly improve the equality of access into the rooms.
Easy to use externally supplied equipment	**Power point to space ratio**	This ratio is quite high at present due to the rooms being computer labs, and therefore requiring sufficient power points to supply a significant number of computers. However, the power sources are currently installed onto the desks, reducing furniture mobility. It would be better to install wall-mounted power points.

	Projector to space ratio	The rooms are currently not fitted with projectors, meaning this feature needs to be added.
	Wi-Fi availability	Wi-Fi is currently available in the computer labs, but reception is often low quality. The cause of this is unknown and diagnosing this issue lies outside the scope of this project. However, the current system fulfils this requirement relatively adequately as there is quite consistent Wi-Fi availability in the rooms at present. There is, however, potential for improvement.
Be visually attractive	**Lighting**	The lighting requirement is satisfied as current lighting must adhere to the Australian Building Codes Board's guidelines regarding Schools (which includes universities). This means the artificial lighting has to provide 320lux (ABCB, 2008), which satisfies the target value. Furthermore, there is ample natural light penetrating into the rooms (see Figure 1), with window size 2m high and 0.9m wide and 11 windows in E101 and 10 windows in E142. Note that E141 only has two windows due only one wall leading to the outside, and in order to provide more natural light the wall between E141 and E142 would need to be removed, which is outside the scope of this project.
	Colours used	Currently there is only one neutral beige colour used for all walls in all three rooms. Though beige can accentuate more stimulating colours, as a standalone it can be quite dull and conservative (Pioneer Trails, 2014), hence unattractive.

From the above evaluation of the current system, it can be seen that the current system fails to meet a significant number of design requirements. Notably, the current system is very poor at meeting the two highest priority design requirements regarding collaborative learning and accessibility. This indicates that a new design is in the client's interests and validates an attempt to generate new designs to occupy these three rooms. However, it should also be noted that lighting, Wi-Fi and power point to space ratio attributes (though power points should be changed to wall-mounted design rather than desk-installed) are already met in the current system, making it important to try and maintain these already-fulfilled attributes.

Scope of Influence

Having established that the current system of computer labs fails to effectively achieve the client's aims for a space that reflects their commitment to collaborative learning, it is now important to define what this report can influence to improve the learning space system. This scoping is helps provide clear definition of what the project should achieve, and what can be controlled to reach that goal (INCOSE, 2006).

For this system, the scope of influence is constrained by two types of system boundaries – physical and design boundaries. Physically, the new learning spaces must be within the spaces currently occupied by the computing labs. The client, CECS, has made it very clear that the regions beyond the computer labs are not to be altered in the course of this project.

The second set of boundaries is defined by what the design process can realistically control when considering design features. For instance, lighting and furniture are within the control of the space designer while construction speed and user behaviour in the space cannot be realistically controlled in the design process.

Table 1 shows a summary of the system's boundaries. Note that in Table 1, the 'Endogenous' column contains those factors that the design can realistically control. The 'Exogenous' contains factors that cannot be controlled but directly affect the system while the 'Outside' factors can be related to the system but will not have any direct impact.

Table 6 System Boundaries for Learning Space System

Included (Endogenous)	**Excluded (Exogenous)**	**Outside**
• Space amenities (e.g. power point placement) • Space furniture • Space colour • Space lighting • Entrance size and features	• User Traffic • User Behaviour • User Purposes (e.g. subjects or classes held) • Power Supply • Construction speed • Cost • Funding • Space's opening hours • Space size	• Other learning spaces (e.g. current lecture theatres) • Area outside of physical learning space boundaries

It is worth noting that many of the factors have been defined as 'Exogenous'. This is because this project is solely concerned with the design of the learning space, meaning that many factors that have a significant impact on the space are not within the project's influence. For instance, funding and power supply are dependent on the ANU's resources (which is beyond this project's scope of influence) while the way in which the space is used is dependent on the user and cannot realistically be controlled by the designer, though well-planned designs can encourage certain user practices (Lockton et al., 2010). For instance, mobile seating and tables would encourage constant rearrangement of the learning space to best suit user needs, in line with the client requirement for active collaborative learning.

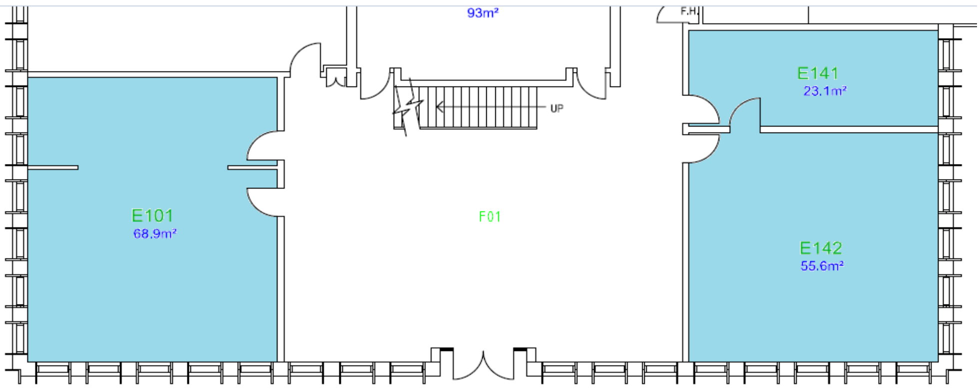


Figure 3 Schematic diagram for ANU Engineering Building foyer area, highlighting regions to be redesigned (E101, E141, E142) in light blue (Adapted from Source:)

For reference, E142 is shown in Figure 1, E141 is shown in Figure 4 and E101 is shown in Figure 5 below.

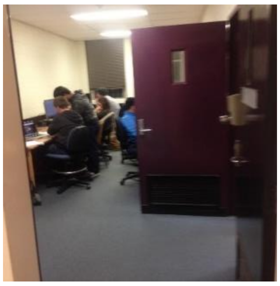


Figure 5 Room E141 from ANU Engineering Building schematic (Author contribution)

Figure 4 Room E101 from ANU Engineering Building schematic (Author contribution)

Logical Description of System

In order to continue furthering our understanding of the desired learning space, it is important to understand how the space is to be used.

One important method to understand this is the development of a Use Case, a specific scenario of the system being successfully used, which provides a high-level description of the system's functionality (INCOSE, 2006). For the learning space, the primary actor is defined as the learning space user. The main success scenario component of a Use Case Diagram for this system is shown below.

Main Success Scenario:

1. Space User decides to use learning space
2. Space User enters learning space
3. Space User selects or creates an area within the space that suits their needs
4. Space User finds all facilities (technological and physical) function as expected and are compatible with external devices brought into the space
5. Space User is able to complete task(s) in an collaborative and functional environment
6. Space User is easily able to depart Learning Space or continue peer interaction

Figure 6 Main Success Scenario (from Use Case Diagram, Appendix A)

A more thorough Use Case Diagram, including support measures if certain system elements fail, is included in Appendix A. Note that the, as expected, the primary actor is a key stakeholder. The other main stakeholders are the client, CECS, who are interested in the new space better reflecting their commitment to collaborative learning, and ANU, who are interested in minimising costs as they will need to provide funding. However, the aims of CECS will be achieved if their requirements are fulfilled, which directly correlates to achieving the use case. Meanwhile, though ANU is a key stakeholder through funding, the lack of clear information regarding funding and the fact that this report has no influence over funding means that their concerns fall outside the project scope.

Functional Processes and Necessary Subsystems

Each of the logical steps taken by the user in the main success scenario was then reduced into functions, expressed using Functional Flow Block Diagrams (FFBDs), shown below. The functional flow block diagram allows the overall system performance to be decomposed into easily traced and separate functional steps, which will also assist in identifying necessary subsystems that need to enable each function (US Dept Defence, 2001). Note that the first step of the user deciding to use the space was not included in FFBD format. Instead this step was deemed to be reliant on user needs and the visual attractiveness of the space, making it a product of system attributes of visual attraction rather than the consequence of any particular function.

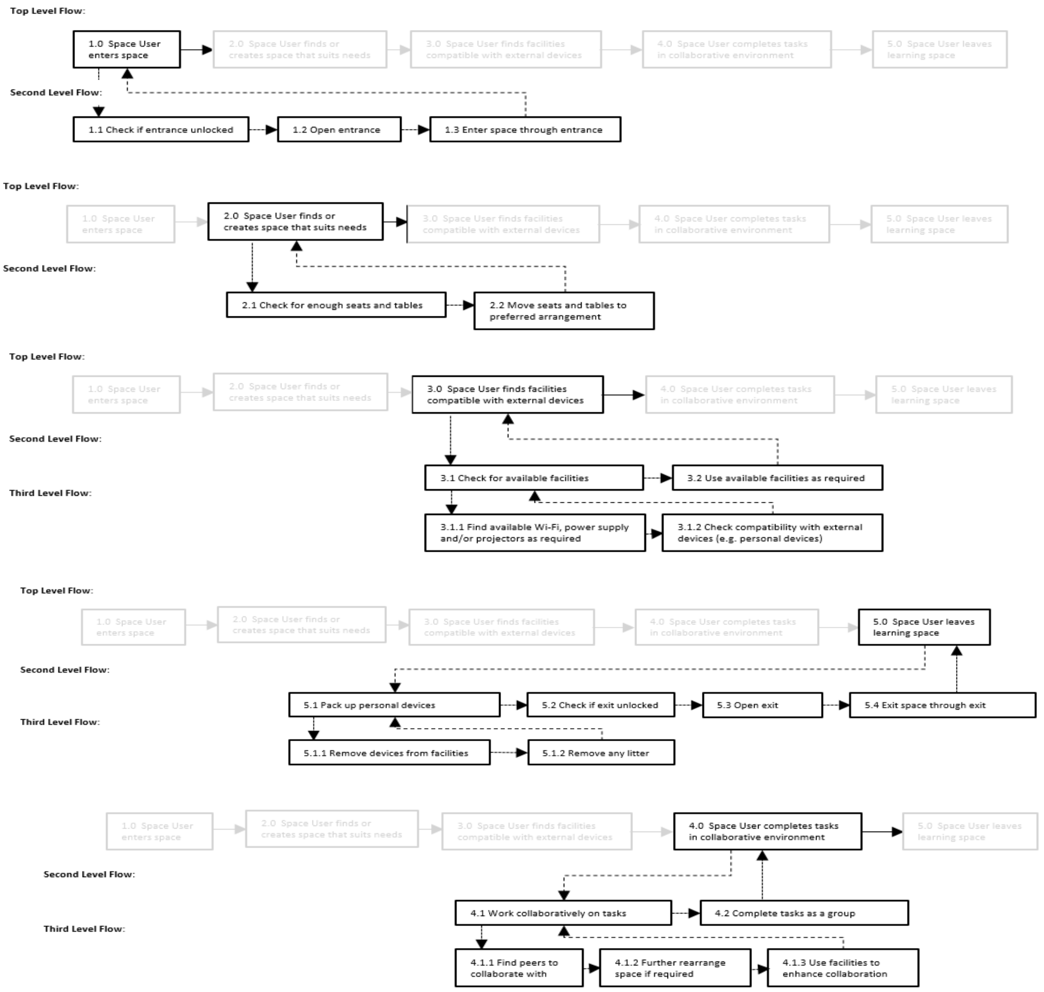


Figure 7 Functional Flow Block Diagram for Learning Space System

Having identified the main functions of the system, it is now important to ensure that the system is able to provide the user with these functions through its subsystems. This process of functional allocation is important in determining which subsystems should be responsible for which functions (Wright et al., 2000), and is expressed below using a modified attributes cascade format that links design attributes, functions and subsystems.

Table 7 Attributes Cascade for Learning Space System

Design Requirement	Design Attribute	Related Function (numbers refer to Figure 8)	Related Subsystem
Encourage collaboration between users	Number of sightlines	2.1, 3.1, 4.1.1, 5.1.2	Seating, Desks
	Furniture mobility	2.1, 2.2, 4.1.2	Seating, Desks
Easy to access	Size of entrance	1.1, 1.2, 1.3, 5.2, 5.3, 5.4	Entrance
	Number of entrances	1.1, 1.2, 1.3, 5.2, 5.3, 5.4	Entrance
	Number of automated entrances	1.1, 1.2, 1.3, 5.2, 5.3, 5.4	Entrance, Electrical
Easy to use externally supplied equipment	Power point to space ratio	3.1, 3.2, 5.1.1	Electrical, Seating, Desks
	Projector to space ratio	3.1, 3.2, 5.1.1	Electrical, Projector hardware, Seating
	Wi-Fi availability	3.1, 3.2	Electrical
Be visually attractive	Lighting'	4.1.1, 4.1.3, 5.1, User decides to use space*	Electrical, Windows
	Colours used	User decides to use space*	Walls, Windows, Seating (colour), Desks (colour)

***As mentioned earlier, the user decision to use the space was deemed a consequence of visual attractiveness rather than being due to any particular system function that the decision could be broken down into. However, the decision itself can be viewed as a function based on visual attractiveness, which is why it is included as a related function.**

It can be seen that the subsystems of 'Seating' and 'Desks' are related to the most number of requirements and functions, with 'Electrical' and 'Entrance' subsystems being the next most relevant subsystems. Other subsystems identified were 'Windows', 'Projector hardware' and 'Walls'.

Concept Generation and Exploration

With subsystems now established, it is now possible to explore design options for each system through a concept generation process. This process will serve to generate a diverse set of design concepts, with this diversity increasing the chance of revealing novel and innovative solutions (Daly et al., 2013). In order to further assist concept generation, inspiration was sought from currently innovative collaboration spaces at tertiary institutions such as the University of Queensland (UQ) and Harvard University.

Firstly, the 'Seating' and 'Desk' subsystems have been identified as highly relevant to the client requirements for the system. Currently, wheeled swivel chairs and rows of rectangular tables (120cm long by 90cm wide) are in use. The tables are too large to be easily moved, especially due to the wiring attached to the in-built power points, and the chairs, though mobile, are quite large (seatbacks reaching 90cm height) and can reduce sightlines due to their height and bulkiness (50cm width).

In terms of seating, concepts that maintained furniture mobility (whether through wheels or low weight) while reducing bulkiness were deemed concepts of interest. One interesting concept is

Ottoman stool designs, which can be wheeled (Appendix B). These are around 40cm in diameter and height (Buy-Rite, 2009), and the absence of a backrest increases visibility of other people, encouraging peer interaction while making it easy to stand up and move around when necessary instead of being restricted by arm rests. They are also lightweight at less than 5kg (IKEA, 2015) (Houzz, 2015), allowing high mobility even without wheels. The variation in colour for Ottoman and their uniform appearance also allow them to double as a second source of colour variation in the space. Another seating option would be two-person benches made out of lightweight materials. These again provide an option to introduce additional colours while remaining mobile and avoiding the visual obstruction of backrests. However, these would be slightly harder to move than individual Ottoman stools.

One of the most attractive prospects for desk designs is a novel commercial product called a Scribble (Burgtec, 2013), produced by Burgtec architects, currently used at UWA (UWA, 2013). It is essentially a high-mobility (4-wheeled) whiteboard surface table with table surface dimensions 900mm by 900mm (see Appendix B for more information about Scribble). This product fulfils the client requirement for high mobility furniture while also providing a clean and novel appearance that helps fulfil the requirement for visual attractiveness. Another design feature of importance for desks is circular desks, as observed in collaborative spaces such as UQ's Collaborative Teaching and Learning Centre (UQ, 2008) and Harvard's B-30 Collaborative Learning Space (Harvard, 2015). This emphasis on curves reduces barriers created by corners and is therefore conducive to collaborative work by maximising group participation (Zhu & Argo, 2013). It would be interesting to see a circular Scribble in the future, however at present both the standard Scribble and circular tables are viewed as sound concepts to apply to the final design.

This above idea also emphasised the importance of utilising whiteboards in the new design. The importance lies in the fact that the present digital enables people to carry image capture devices on their person almost all the time (e.g. smartphones). This means space users can capture ideas by hand, increasing the ability to incorporate free-drawn diagrams to express ideas, while having the image capture resources to allow the information to be immediately stored digitally. The surface can then be cleaned, creating a virtually unlimited writing surface without worrying about losing previous ideas, as they have already been stored digitally. This led to the design decision to include both conventional standing whiteboards and novel Scribble tables to maximise whiteboard surfaces.

The entrance subsystem is also very important in fulfilling the overall client requirements. It was decided that larger entrances were more important than more entrances, based on the HoQ that showed increasing entrance size would benefit three client requirements compared to only one for increasing the number of entrances. Automatic entrances would need to be introduce to facilitate disabled access. However, this would also require a source of power, making automatic entrances also dependent on the electrical subsystem. In terms of the actual design of the door, either sliding or swinging doors could be used. In this case, sliding doors would be preferable as they do not occupy additional space when opening or closing, allowing the space to maintain the largest area possible. This helps to facilitate furniture mobility by maximising floor space and also makes it easier to move external devices into the room as there is no need to make way for an opening door. It also helps to avoid reduction in sightlines that can be caused by an obstructing door.

In terms of the other electrical subsystems, the Wi-Fi and lighting attributes have already been met by the present system. However, it is worth noting for any potential design that incandescent light is preferable to fluorescent as research that indicates fluorescent lighting has adverse effects on learning outcomes. Also, natural light best optimises student performance (Vic Gov, 2011).

For another electrical subsystem, the projector subsystem, the main design decision lies in the actual position of the projector hardware (note that the screen will be placed at the front of the room to allow maximum visibility). The main locations are desk top, wall mount or ceiling mount. For this design, ceiling mount is preferred due to not impeding furniture mobility (desk top mount would require one fixed desk in the middle of the room) while being able to be placed close to the projector screen (wall mount would be on far opposite wall to screen). Power points, another electrical subsystem, have the design options of being installed either in walls or desks. Though desk-installed power points are good at ensuring efficient power supplies for users, they restrict desk movement. Seeing as mobile furniture was deemed more important than power supply in the HoQ, a trade-off decision was made to prioritise furniture mobility over power availability, leading to the design preference to install wall-mounted power points.

The subsystem 'Windows' does not require any significant change as the natural lighting at present is adequate. One suggestion that may help to improve the visual attractiveness of the space would be to remove the cage-like protective barrier outside each window as this creates a restrictive feeling on those within the learning space. Meanwhile, the wall subsystem can only be superficially changed through repainting, making colour choice the main design concept for this subsystem. In this case, the colours should produce an unthreatening and stimulating environment to enhance learning (Daggett, 2008). Recommended colours include blue and green, associated with collaboration, creativity and thoughtfulness, while having a low colour contrast to reduce eyestrain (Daggett, 2008).

Using these concepts, potential designs were generated for each room, as shown below:

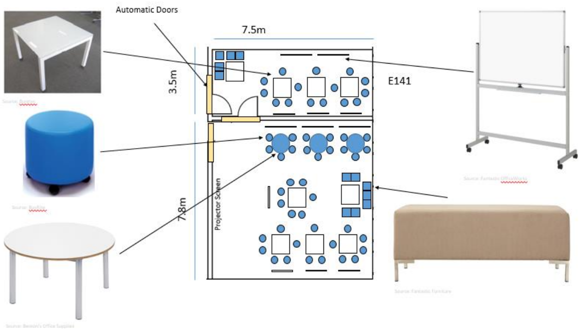


Figure 9 Potential room designs for E141 (upper) and E142 (lower)

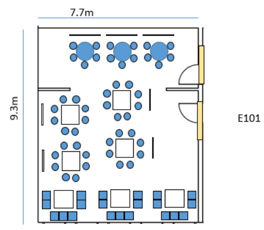


Figure 8 Potential room redesign for E101

Assessing Change

Although some concepts of interest have now been generated, it is imperative that there be a way to assess whether or not any new system that is used actually better fulfils the client requirements. This process may also reveal overlooked design errors, such as compatibility between concepts that appeared to mesh well theoretically (Hitchins, 2007). This particular report is not focussed on conducting any testing of the system but is interested in designing methods by which a new system could be evaluated. For this particular system, there are two main stages of testing that should be applied to the system. These recommended main testing stages are pure design-level testing, a prototype level test, and operational testing.

Firstly, considering pure design-level testing, the purpose of this testing would be to serve as a validation phase, or proof-of-concept, to help ensure that the designs considered are backed by genuine target population interest. For this system, the target population would be ANU engineering students (and staff to a lesser extent, as staff have their own offices). Methods to implement this level of testing would be:

- Surveys, which are already an established method used by CECS to receive student feedback. Response rates can be enhanced using incentives like movie ticket prizes.
- Social media, such as a Facebook page devoted to progress on the new learning space project, which could act as both a place to observe general student interest in the project and as a platform to ask students for feedback.
- Online or physical forums hosted by engineering Student Representatives, which could provide more interactive feedback and allow the target population to voice any concerns

Ways to analyse this information would be to set minimum benchmarks for information such as approval rate based on the surveys and/or forums (even Facebook ‘likes’) and use this as a target value to assess whether the design passes the pure design level testing.

If a design adequately meets client requirements and is then approved during the pure design level testing, then prototype level testing should be conducted to confirm that the system functions as expected and that no glaring oversights have been made. For the learning space system, a prototype would entail temporarily transforming one of the three computer labs into the envisioned learning space design over a trial period of two or more weeks. This time period will give students sufficient time to learn of the trial learning space and for a significant number of students trial the space. This trial method also presents an opportunity to generate further interest among the target population, which may assist in convincing funding bodies like ANU that the project will have immediate benefits.

Finally, operational testing would essentially be an ongoing process focussed on assessing the performance of the system under realistic conditions and seeking out ways to improve the system under these conditions (US Dept Defence, 2001). The importance of this testing stage lies in the fact that the client requirements for a visually attractive space that encourages collaborative learning will require the space to avoid growing stale, which means the space needs to continually improve rather than allowing the initial design to remain untouched. Additionally, this level of testing should be conducted at regular intervals (possibly once per year) and should be complemented with an active process of seeking student feedback in order to give the target population the time and ability to reveal necessary improvements and to voice these. Operational testing conducted in the above outlined manner also allows system upgrades through support and maintenance phases by providing regularly updated information that gives these phases a sound design direction. This will be especially true for minor improvements that can be implemented during support and maintenance processes.

Lifecycle Analysis

The above processes will lead to the selection and implementation of a new design for the space currently occupied by computer labs in the engineering building. However, once the system has been implemented it is imperative that the lifecycle of this new design (or solution) be considered in terms of maintenance and support, as well as end-of-life planning (Gibson & Scherer, 2007). This will serve to improve the sustainability and lifetime of the solution.

Support and maintenance should serve as an ongoing and regularly practiced process that helps keep the optimal system performance while providing an opportunity for periodic upgrading (Hitchins, 2007) (Gibson & Scherer, 2007). As has already been mentioned for this system, support and maintenance can be utilised alongside regular operational testing/evaluations of the system in order to allow the system to be upgraded according to user feedback. The learning space is quite modular, or functionally independent of one another (Gershenson et al., 1997). For instance, the furniture subsystem can be modified without necessitating a change in the entrance or electrical subsystems. The only examples where this is not the case are the relationships between the electrical subsystem and the projector and automated entrances. However, even then the electrical components associated with the projector will not be the same wires as those connected to the entrances, so alterations to the projector's electrical attributes will not affect the entrance and vice versa. This modular design will greatly extend the longevity of the solution as improvements and repairs can be made to any one subsystem without having to reconfigure the rest of the system, which will minimise financial and human resource costs for maintenance and support.

The most likely forms of ongoing maintenance and support that will be required will be cleaning, electrical maintenance and physical repair work. The current cleaning system used by the client should suffice for the system, with regular cleaners contracted to the clean the space. Electrical maintenance here refers to both maintenance of the power supplies and maintenance of Wi-Fi connectivity. Most likely, the latter will become a more common source of complaints, with these most likely being handled by the university's IT Services. However, power supply failure is also a possibility, and power points should be checked for performance and any student complaints acted on, due to the importance of a functioning power point in facilitating digital age learning. Finally, depending on how careful users are, physical repair work will need to be conducted at regular intervals but not too frequently (once per semester or year) to ensure all furniture is still in working order. Fines can also be used to discourage careless user behaviour and thereby minimise maintenance costs. It would also be advisable to include more immediate response maintenance work in case of significant issues revealed through student feedback. For instance, unusable furniture or safety hazards should be immediately dealt with rather than waiting for the next maintenance round.

Aside from support and maintenance, the other essential element of the system lifecycle is end-of-life planning. This learning space can be divided into three end-of-life components – material components, space component and intellectual design component.

Firstly, the material components of the system will consist of furniture items (e.g. items recommended during concept generation) and some potential IT items such as Information Commons computers. End-of-life plans for these items revolve around material recycling, reselling and/or philanthropic giving. Material recycling for furniture is possible through programs such as The Green Shed in Canberra (Green Shed, 2015) which reduce landfill by giving away second-hand goods, while IT products can be recycled through initiatives like OfficeWorks' Bring IT Back program (Officeworks, 2013), which can regain up to 98% of materials from retired goods. Resale for both furniture and IT could be as simple as internal second-hand price sales to students and staff, while IT products also often have commercial resale schemes and partnerships such as the Apple recycling program that gives back a fair market value price on any recycled Apple products (Apple, 2015). Philanthropic giving can be used to strengthen institutional and community relationships by giving furniture or IT products to partner or feeder schools. Philanthropy can also be used to enhance institutional reputation, such as by donating to well-known charities like Vinnies (St Vincent de Paul Society, 2015) to boost ANU's (or even specifically CECS') reputation.

The space component refers to the actual space occupied by the learning spaces, in other words rooms E101, E141 and E142. Effective sustainable end-of-life practices when dealing with the space component would be further repurposing or even clearing the space altogether. The first of these two options would be to redesign the space to perform a new function and thereby provide for a new target population. For larger scale changes, it would be possible that the rooms would be completely cleared and a new building constructed over the current space. This would be a more drastic end-of-life scenario and the new space would be dependent on the purpose of the new building.

Finally, the intellectual design component of the system here refers to the actual conceptual design of the learning space. This component of the system can also be treated sustainably through information dissemination, whereby other institutions seeking to design learning spaces for their own needs can take inspiration from designs used by CECS. This open knowledge-sharing approach would be more productive than any effort to protect the intellectual designs of the learning space by helping other institutions looking to improve. The reality of these benefits can be seen through this very report, as many concepts were inspired by other tertiary institutions that made their learning space ideas available online. Furthermore, this spirit of collaboration further fulfils the client (CECS) requirement that the learning space reflect collaborative learning, as an open sharing of intellectual designs creates the potential for inter-institutional collaboration and dissemination of knowledge.

Design Communication

The above report outlines important design criteria and potential concepts (including one potential solution design set) that can be used to serve the client's requirements to improve the ground floor computer labs in the ANU Engineering Building. The client, College of Engineering and Computer Science, should take note of the guidelines and concepts generated in this report and take this a step further to explore even more potential designs, remembering to constantly evaluate against design requirements. Also, concept generation will be more easily directed once budgeting and funding is known, as this has been to ambiguous to be part of the project scope for this report. However, an approximate pricing estimate has been included in Appendix C to give a rough idea of costings for the project. Once a design and funding have been confirmed (including target population feedback), the next steps required would be to find ANU approval, professional construction approval and to contact suppliers and installation personnel. During this period, the necessary support and maintenance should also be organised in order to ensure the new learning space system provides both desired performance and longevity.

Appendix A

Complete Use Case Diagram:

Primary Actor: The Space User

Scope: The Learning Space

Level: Summary

Stakeholders and Interests:

The Space User – Be able to use an easily accessible space that encourages collaboration and is comfortable to work in

CECS – Have a learning space that reflects their commitment to collaborative education

The University – Invest in low-cost, low-maintenance learning space that is popular, low-risk, increases public image, and has a long lifetime.

Minimal guarantees: The learning space will be open to student access

Success guarantees: Space User able to use easily accessible and comfortable space that is well-suited to group work

Trigger: Space User enters learning space

Main Success Scenario:

1. Space User decides to use learning space
2. Space User enters learning space
3. Space User selects or creates an area within the space that suits their needs
4. Space User finds all facilities (technological and physical) function as expected and are compatible with external devices brought into the space
5. Space User is able to complete task(s) in an collaborative and functional environment
6. Space User is easily able to depart Learning Space or continue peer interaction

Extensions:

2a. Learning space is closed: Inform University to increase opening times or enable 24hr access

2b. Space User is unable to access learning space: inform University to address neglected accessibility needs

3a. Learning space fully occupied: move to another learning space

3b. Learning space is too noisy: notify noisy party and rearrange furniture to minimise impact of noise e.g. create workstation away from noisy party

3c. Learning space too noisy for individual work: move to another learning space not focussed on being a space for collaborative work

4a. Space User unable to use facilities (technological or physical) due to property malfunction:

inform University to repair and easily rearrange space to continue working with properly functioning facilities

4b. Space User finds facilities difficult to use: inform University to either improve design or provide easily accessible instructions

Appendix B

Taken from Burgtec website.

Figure 10 Burgtec Scribble whiteboard table (Burgtec, 2013)

Figure 11 Ottoman indoor bench (Fantastic Furniture, 2015)

Figure 12 Wheeled Ottoman stool (Buy-Rite, 2009)

Figure 13 Circular Study Table (Benton's Office Supplies, 2014)

Figure 14 Free-standing whiteboard (Officeworks, 2015)

Appendix C

Table 8 Estimated costs for learning space system

Item	**Unit Price ($)**	**Number of Units**	**Total Price ($)**	**Source**
Scribble Table	*100	16	1600	Burgtec
Freestanding Whiteboard	100	19	1900	Officeworks
Ottoman seat	60	91	5460	IKEA
Rectangular bench	200	33	6600	Fantastic Furniture
Entrance	*1000	5	5000	Estimate
Circular Table	220	6	1320	Benton's Office Supplies
Total Cost			**21880**	

*Scribble and Entrance prices were estimated as they require actual quotes to be made – estimated prices would be a minimum estimate

Considering that the costs listed are for the items themselves, the cost can be assumed to be at least double when installation and moving costs are factored in, giving an estimated price of over $40000

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