Participating in the Communication of Science: Identifying Relationships Between Laboratory Space Designs and Students' Activities

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Abstract

Learning spaces can play a powerful role in shaping and supporting the activities of the students and teachers who use them: they can be agents for change when the success of new pedagogical approaches depends on shifting entrenched practices. The laboratory is a key site for science education. It is here that discipline knowledge and generic competences are fused and honed, in the very act of 'doing science'. This paper focuses on communication of science. It looks at how students learn to participate in science communication, and acquire both scientific and more generic communication skills, while engaged in laboratory-based activities. This paper reports some findings of ethnographic research that involved observing student activity in laboratories. This opportunity to examine differences in patterns of communicative activity arose from a relocation to new purpose-designed laboratory spaces. Ethnographic research is appropriate for gathering data about space usage. It helps trace relations between student activity, characteristics of the spaces in which the activity is unfolding, the social organisation of the work being done, and the disciplinary practices that underpin the tasks that students are set. Our research identifies the importance of sightlines, communication tools and instructor behaviours in promoting students' communicative activity.

Introduction

The transition from novice learner to expert practitioner often takes many years of undergraduate education, graduate education and workplace experience. Development of mastery in a discipline area involves acquisition of a robust, flexible understanding of the discipline's conceptual knowledge base and competence with its practical procedures. It also involves a range of transferable, generic skills, such as the ability to work as a member of a team, exercise autonomy, initiative and leadership, and act ethically and according to professional standards. These generic skills also include the ability to communicate, using a variety of methods, to a range of audiences. The acquisition of communication skills is the focus of this paper. Communication skills are not treated as independent from other aspects of learning to be an expert practitioner: they are inextricably connected, and need to be developed in the *doing* of science. It is through experiencing apprenticeship in the *doing* of science, through legitimate peripheral participation in scientific communities, that students learn the ways of *knowing* in science and the ways of *being* a scientist – embodying the practices of science (Lave & Wenger, 1991; Brown, 2006; Dall'Alba, 2009).

In the higher education context, undergraduate science students learn science by 'doing science' in the classroom laboratory. The laboratory provides the setting for tasks and instructional approaches that facilitate practical application of theoretical concepts and key principles in a discipline. Laboratories create opportunities for students to apply knowledge in 'real world' and experimental contexts and to engage in practices similar to those of experts (deHaan, 2005). The laboratory also provides support for a social network for learning science, collaboration is encouraged and students often work in teams on common problems working towards common outcomes. These teams evolve the social, intellectual and human capital to create problems, solutions and outcomes in research-like settings in ways that cannot be achieved by individuals alone. Classroom laboratories can be likened to learning studios which promote collaboration in learning as students and staff acquire skills from each other, and learn from each other's mistakes (Brown, 2006). In this way, students become creators and constructors of their own knowledge using the means by which scientific knowledge is created and constructed in practice, through open-ended scientific enquiry, exploration and discovery within a curriculum that facilitates and enables research-like experiences (McWilliam et al., 2008). Thus, there are particular ways in which science is communicated and in which students learn to communicate as scientists.

We define communication of science as the ability to articulate, exchange, discuss and convey scientific ideas and concepts, in a way that reflects knowledge practices in the sciences. Learning to communicate science as a scientist in training is important because it facilitates discourse on, and insight into, science as a method of enquiry employed in the discovery and understanding of new knowledge. It is also a valuable skill for graduates to be able to transfer into workplaces, research or further education. Moreover, it facilitates the dissemination of complex knowledge to audiences, including those not trained in scientific enquiry where translation into a suitable form of language becomes necessary.

Many methods and interventions have been used to incorporate or integrate science communication skills into science curricula through explicit instruction and evaluation. Initiatives have included instruction and assessment of communication of science through introduction of novel tasks that reflect the different genres of science writing to non-scientific audiences (Poronnik & Moni, 2006), or that require students to contextualise research findings and offer a commentary on them (Moni et al., 2006). Others have incorporated training in written communication skills in the context of the science curriculum (Brownell et al., 2013a; 2013b), or recommended methods to adapt curricula for direct instruction and assessment of science communication skills to address employer needs (Gray et al., 2005). In many instances however, communicating within the sciences is *implicitly* expected, but not formally taught or assessed. Curricula evolve to incorporate essay and report writing tasks, oral presentations and other communication modes, and the communication of science as a skill is acquired tacitly.

We propose a novel means by which communication of science can be evaluated *in situ*, using a framework that analyses emergent learner activity in specially designed learning spaces. Development of knowledge and skills, such as communication skills, in science occurs through 'learning by doing' in specialised learning spaces (classroom laboratories). Crucial to the current study is the concept that spaces are themselves agents for change and changed spaces can help change practices (Shove, 2012). The power of *built pedagogy* is increasingly evident. New spaces can act to define how one learns and teaches while simultaneously providing an integrated learning environment (Kolb & Kolb, 2005; Oblinger, 2006). Examples of such built pedagogies include the expansion of hybrid education where curriculum merges in virtual and physical space, design of collaborative learning spaces (e.g. learning studios), flexible learning spaces (for multiple types of learning activities), technology-supported learning spaces and the use of technological innovation as an enabler for change.

The University of Sydney, using the Charles Perkins Centre as a vehicle, has made a significant strategic commitment to creating an environment to enable the emergence of a new model for transdisciplinary engagement across the campus. The Charles Perkins Centre provides a multi-faculty, transdisciplinary research and education 'Hub' where academic, technical and support staff and students converge in one building for research and education activities. Learning and teaching spaces in the Charles Perkins Centre Hub were designed by all stakeholders involved in using them, and have been devised as collaborative and/or flexible learning spaces (Figure 1). They provide opportunities for learning in small and large groups, with cohorts from multiple disciplines (including biomedical, veterinary and health sciences, and molecular biosciences), different years of candidature, as well as a range of units of study and degree programs. They allow academic, technical and support staff to work side by side. The design of all classroom laboratories in the Charles Perkins Centre Hub kept in mind the integration of research and teaching with the aim of increasing students' scientific enquiry capabilities and research competencies.

Figure 1. The X-Lab, a collaborative, multi-disciplinary learning space in the Charles Perkins Centre Research and Education Hub at The University of Sydney.

While there is a body of work reporting on the evaluation of flexible and collaborative learning spaces (e.g. Cennamo & Brandt, 2012; Cox et al., 2009; Harrop & Turpin, 2013; Roberts & Weaver, 2006; Tregloan, 2009; Wilson & Randall, 2012), technology-enhanced and research-enhanced spaces for multi-faculty and transdisciplinary learning and teaching are relatively new. Research into the ways these spaces, and their modes of use, influence learning and curriculum is still rare and the present study begins to fill this gap.

The conceptual framework for the current study was developed for the analysis of complex learning environments (Goodyear & Carvalho, 2013; 2014), where the focus for analysis is *learner activity*. It is well-suited to analysing situations in which students' activities are not tightly controlled by teaching staff. In situations where students exercise significant autonomy, their activity is best understood as *emergent*, rather than pre-determined. It is shaped by three sets of influences, whose effects converge in complex ways. Activity - what students actually do - is shaped by (1) the tasks they are asked to tackle, (2) the physical setting, and (3) the social organization of their work (e.g. how tasks are distributed across members of a team). While tasks, setting and social arrangements can be designed in advance, learner activity cannot. The *tasks* students are given emerge from a process of *epistemic design*, which in turn reflects the way that knowledge is structured in the discipline/profession concerned and by its characteristic working practices. The *setting* includes material (tangible), digital and hybrid spaces, equipment, tools and artefacts and other such resources for learning. *Set design* includes creating appropriate configurations of physical resources and elements of the space, aligned to structure and support the students' anticipated activities. *Social design* addresses the social organization of students' work and covers such things as the allocation of roles and suggested divisions of labour.

These three kinds of design components do not act independently. They interact at 'learntime' and the relationships between these elements and the learners' activities can lead to the acquisition of competencies and outcomes that may not have been intended or anticipated. Changes in the design of the tasks, setting and social arrangements may alter student activities in ways that facilitate or impede learning. Moreover, students themselves usually play an active role in reconfiguring the physical and social arrangements in which their activity is situated. Tracing paths of influence between what has been designed, what students do and what they learn from what they do is challenging, but essential.

Using the analytic framework described above, we sought to explore how the teaching and learning of science communication skills takes place in undergraduate science education. We observed student activity in two sets of laboratory spaces, older discipline-specific spaces, and new multidisciplinary, technology- and research-enhanced spaces. In part, this was to obtain a clearer understanding of the specific benefits to the acquisition of science communication skills that might be associated with design features of the new learning spaces in the Charles Perkins Centre Hub.

In the research reported in this paper, our focus was on students' engagement in science communication activity. This is best approached through close observation of activity *in situ*. It is very difficult to comprehend the *meaning* of what is observed without a deeper knowledge of the perspectives of participants and so the broad approach taken by the team is best described as ethnographic observation. This seeks to understand the meshwork of participants' practices, skills, ways of knowing, resources, rules and values.

Methods

Ethnographic observation is a qualitative research method which permits the close examination of, and sometimes participation in, practices *in situ*, i.e. within the 'real world' or lived context in which the practices occur and evolve. Observations have been conducted over two semesters, in two sets of facilities at the University of Sydney. The older set of facilities is discipline-specific. That is, they were designed, managed and have evolved as facilities tuned to the needs of particular discipline areas. The new set of facilities in the Charles Perkins Centre Hub has been designed and is managed as a multidisciplinary space. The observations reported here were carried out in the immediate post occupancy period – in the first semester of use.

Observations were carried out over a total of 40 hours, on cohorts of students from units of study in pharmacology, physiology and immunology. Class sizes varied from ~20 to 100, while cohort sizes varied from ~60 to 250. Observation of activities in the older discipline-specific spaces occurred in (1) custom-built computer laboratories as well as multi-purposed spaces where desktop computers were located around the periphery of the classrooms, and (2) traditional classroom laboratories equipped with the basic equipment required for conducting 'wetlab' and experimental practical classes. In the Charles Perkins Centre Hub, observations were conducted in (3) the flexible 'dry' laboratories, equipped with re-configurable furniture and laptop computers for individual student use as needed, and (4) the 'X Lab' – a very large 240 seat open plan laboratory designed to incorporate state-of-the-art technologies and equipment in a research-enhanced learning space. Ethics approval for this study was provided by The University of Sydney Human Research Ethics Committee (approval number 2013/877).

The approach to observation took an activity-centered approach (Carvalho & Goodyear, 2013; 2014), informed by theories of materiality (Sørensen, 2009), material ecology (Ingold, 2011) and social practice (Shove, 2012). In tracing the movement of people and things, consideration has been given to pedagogy and place, with the intention of describing how materials participate in practice and the ways in which arrangements of the material and the digital point to valued activities (Sørensen, 2009). The materials described here include "the networks of interacting people, objects, activities, texts etc. that shape learning activities and outcomes" (Goodyear & Carvalho, 2013). The data recorded consisted of field notes and sketches. Observations of communication of science *in situ* included capturing:

- the amount and effectiveness of interactions between students, and between instructors and students;
- the types and complexity of questions being asked by students and instructors;
- students' ability to outline problems or solutions;
- how students worked through complex, open-ended problems;
- analysis of the use of technologies and communication tools (whiteboards/walls) and the way the content of the whiteboards/walls was altered over the course of the learning activities (Cox et al., 2009; Powell, 2009), and
- the willingness of students to re-configure their environment, and the frequency with which they did so, in order to facilitate their own activities and improve communication.

Purposeful sampling of students in the different sets of classroom laboratories provided a broad set of observations gathered across the multiple spaces, focusing on the way student autonomy is supported and encouraged in these spaces. Together, these observations provide both breadth and depth: they offer a "thick description" (Geertz, 1977). The next section of this paper draws selectively from our observations to illustrate some key relationships between attributes of the designed spaces and students' activity, especially their engagement in science communication activities.

Results

Emerging from ethnographic observations of student activity in both the older discipline-specific (1 & 2) and new Charles Perkins Centre Hub learning spaces (3 & 4) were key elements of the physical design, task design and social design that influenced communication of science by students and instructors *in situ*. These design elements included the 'set up' (physical and virtual configuration) of workspaces, allocation of resources and equipment, the appropriate use of desktop vs laptop computers, the use of whiteboards/walls in task design and execution, the static or dynamic nature of the social arrangements as a consequence of physical and task design elements, and the quality of interactions between instructors and students.

The learning situations, across all the spaces observed, generally involved (a) an introduction by an instructor to the context and tasks to be undertaken in the formal learning session, followed by (b) students tackling a series of tasks, using experimental instrumentation and equipment as well as computers (in the 'wet' laboratories) or using computers for simulation activities or self-driven tutorials (in the 'dry' and computer laboratories). Activities were based around scientific enquiry into a particular concept or set of concepts that students were anticipated to come to an understanding of through engagement in the tasks, and communication about them in the process. Additionally, where relevant, students were expected to demonstrate new practical skills that facilitated construction of their understanding. Most sessions were structured over 3-4 hours with instructors in a 1:15 or 1:20 ratio with students.

Set up of work stations – visibility and communication

The ways in which students engaged in communication activity, and their use of tools (etc) that were intended to support their learning, were affected significantly by aspects of the physical design that impacted on lines of sight. Sight lines affected the mutual visibility of instructors and students, and their ability to maintain eye-contact.

Line of sight appears to be an essential aspect of supporting communication. For example, in custom-designed computer laboratories where workstations are set up in rows, separated by low partitions, using all the available floor space (not just the perimeter of the lab), line of sight is preserved across the space. In this space, it was observed that groups formed readily in the demarcated working zones and students who continued to discuss their tasks, and their developing understanding, were those who maintained line of sight between computer screens, or who were seated physically alongside one another. On the other hand, where desktop computers were arranged around the periphery of the room, such that students were facing the walls rather than the centre, eye contact between instructors and students was much more problematic. This reduced the capacity of both instructors and students to initiate discussions about the tasks and associated concepts. In flexible 'dry' laboratories where desks were arranged in groups rather than lines, a clear line of sight and greater visibility for both students and instructors was offered, facilitating ease of movement between groups of students and maximal eye contact and engagement. Students in these spaces were free to join and leave groups of activity, and could exchange ideas about the tasks and concepts with peers sitting both adjacent and opposite to them, supporting a more collaborative environment.

Even in spaces designed with demarcated working zones containing individual desktop computers, lines of computers induced disconnection when the gaze of student was diverted from the instructor to the screen. In contrast, the grouped arrangement of workspaces, and clear lines of sight, in combination with the use of mobile computing solutions (one user-driven laptop per student) in the new flexible 'dry' spaces greatly facilitated communication of enquiry and conceptual understanding during tasks. This was evidenced by the ability of students to interact with pre-class and in-class digital material, while taking individual notes, and while concurrently checking their understanding and discussing concepts and answers to questions in groups.

Another observation in the customised computer laboratory spaces was that objects of shared attention that are distributed uniformly across multiple screens, tended to shift students' attention away from the instructor, interrupting engagement with the instructor as they explained concepts or tasks. In the cases described here and above, the desktop computer is not an ideal instructional tool: it is tethered, is operated by a single user and averts shared attention. Furthermore, when it does not belong to the user, technical failure creates a shift of responsibility to rectify the situation from the user to some other, thereby reducing the agency of the learner. In contrast, mounted, user driven, moveable desktop computers in technology-enhanced laboratories such as the X Lab (figure 2) played a successful role in communicating task requirements to students, and were deliberately set up to allow access to multiple modes of communication. These included multiple concurrent high definition digital video inputs to each student computer (from the instructor's PC, a face camera and a digital visualizer located above the instructors work area), alongside access to digital and online resources. Where practical demonstrations were projected in real time or through pre-recorded videos on to computer screens or projector screens, communication of task requirements was embodied in the concurrent movement of the instructor's hands, narration of the task and facial expressions. This tight coupling, in real time, which included unexpected outcomes or the successful completion of a series of movements after repeated failure, served to communicate the everyday reality of doing science. Furthermore, where student's computer screens are configured to accommodate the streaming of today's practice, alongside pre-recorded tutorials or demonstrations, online notes, additional sources of information, and customised software to collect and analyse data, these technologies permit the blending of the physical and the digital in ways that were not previously feasible nor even imagined.

Use of tools to enable communication

We observed across multiple learning spaces, both new and old, that those students who utilised the tools made available for communication (such as whiteboards/walls) worked together and maintained group cohesion far better than those who did not. Use of tools for communication such as whiteboards/walls also facilitated social organisation within groups. Students were free to join and leave groups of activity, look at whiteboards/walls and observe others conducting their experiments. Roles also became apparent, as did divisions of tasks. Using the whiteboard/wall as a point of reference, students engaged in discussions about the concepts, their questions and their understanding. Externalisation of enquiry around complex phenomena appeared to make the process of understanding easier, by 'fixing' shared understanding in a legitimated, shared, working space. The whiteboards/walls offered a communal forum in which work in progress could be illustrated, negotiated, altered and

Figure 2. Mounted, moveable desktop computers in the X Lab which allow access to multiple modes of communication, including multiple concurrent high definition digital video inputs to each student computer from the instructor's PC, a face camera and a digital visualizer located above the instructors work area, alongside access to digital and online resources.

accepted – left for all to see; or rejected – annotated, altered or rubbed out. There was also a sense that the knowledge was built up over the course of students' time together. That is, the negotiation of a shared understanding occurred through the iterative *doing* of the task, not merely through solving a textbook problem. The students had to work to gather the information and transform it into a diagram or text that had meaning. It was *their* work and their engagement was visible. This was a qualitatively different type of interaction than what we saw taking place in the absence of whiteboards/walls.

Another interesting observation made across multiple spaces concerned the use of mobile devices to record images, for example from whiteboards/walls, projected images, experiments in process or data captured in real time. Significantly, images recorded during formal learning activities on mobile devices introduce an entirely new dimension to communication of science within a learning setting, providing points of reference for discussing concepts and activities that persist and extend beyond the formal learning session and its site.

The allocation of tools and resources for experimentation and simulations was observed to influence agency in students. Individual allocation of tools and resources in the newer, well-equipped, research-enhanced classroom laboratories appeared to increase student exploration and sense of ownership of the space. Students were not simply 'repeaters' or 'replicators' of demonstrations, but proceeded with their own versions of what was demonstrated, showing an increased willingness to re-configure their environment, experiment and communicate about similarities and differences. In such exchanges, it seemed the materials were waiting and the students were active. This contrasted with observations of the students in the older laboratories, where it was the students who waited whilst access to materials determined pace, progress and communication of enquiry.

Quality of instructor interaction influences communication
A balance was observed between instructor *presence* - to communicate concepts and procedures, facilitate engagement in tasks, elicit understanding, and scaffold enquiry - and *absence* - which promotes autonomy in some cases, but also promulgates disengagement if scaffolding, checking and correction are not provided. It was also observed, across multiple spaces, that lecture-style instruction without active manipulation of tools and equipment or computers led to a reduction in student engagement and participation, and a reduced willingness to discuss processes and outcomes of enquiry.

Different levels of exploration and willingness to manipulate the environment were noted, depending on the role of instructors: as co-configurers in the learning experience, encouraging students to 'have a go', or as dictators of process. Some cohorts appeared to feel very comfortable maneuvering computers, engaging in preparations/set ups and working autonomously while others tended to wait for instruction, and hesitated to begin a task. Active involvement of instructors, sitting next to and amongst the students, not professing but building with them, helping them make connections and communicate their understanding back to the instructor, led to a different quality of interaction, and one which the students appeared to value greatly. Relating the known with the unknown or 'yet to be known', and communicating material in ways that could be related to real life and experimental contexts, engaged students and facilitated discussion around the learning material. Students responded to the expertise of the instructors, often utilising them as resources in more flexible assemblages of tools and tasks. Effective facilitation by instructors was observed to enable evolution of ideas in real time as students were acquiring and consolidating their understanding of the concepts, and communicating their new understandings with each other.

Discussion

This study has begun to explore the influence of learning space design on students' learning, particularly as it relates to communication of science. Communication of science here refers to the ability to articulate, exchange, discuss and convey scientific ideas and concepts, in ways that reflect knowledge practices in the sciences. Aspects of epistemic design (tasks), physical/digital design (setting) and social design were identified that influenced communication of enquiry, concepts and practices *in situ.* As skills acquisition occurs through student participation and engagement in tasks in different settings, elements of the task and space are likely to influence development of these skills. From our observations it is evident that spaces can be designed to improve communication and engagement in learning science, and tasks can be designed to promote the same ends. Moreover, tasks can be designed and executed more effectively if undertaken in appropriate spaces, i.e. physical and virtual spaces designed to optimise communication and engagement in concepts, processes and enquiry.

Our observations showed that spaces designed to reduce physical impediments to communication between instructors and students and incorporate tools for communication (such as whiteboards/walls), work to optimise communication of science processes and concepts as they are learnt. Where visibility and line of sight are maximised, collaboration and communication prosper, and students spontaneously organise themselves into activity and discussion groups. Our findings echo those of Hunley and Schaller (2009) and Lee and Tan (2011) who observed that engagement was encouraged by learning spaces that were deemed to be open, flexible, comfortable and appealing to the emotions. Regarding the use of communication tools, we surmise that objects of shared attention permit visibility of thinking in a way that unifies thought, lets students scaffold their enquiry and learn from each other's questions and answers. A real sense of shared endeavour was present when students worked to solve something that had been externalised on the whiteboard/wall, compared to when they were discussing something that was verbalised but not seen. There were at least two things at play here: ownership and visibility. Negotiating and making semi permanent and public the responses to tasks reveals the act of communication to everyone. Fixing dialogue long enough to work on misconceptions, negotiate changes to what is written, and alter the representations in a public space is an intrinsic aspect of communicating science. The use of these particular aids to communication promoted a sense of ownership: of the tools, the spaces and the processes of negotiating shared meaning. Furthermore, the manner in which they made the student's thinking visible provided instructors with ambient feedback, prompting further discussion about misconception, and students with insight into the responses of their peers. Failure to engage in this type of endeavour is also highly evident in these interactions, providing additional cues for instructors to redirect unproductive activity and work to increase levels of engagement. In these ways students are responsible for building their own and the collective knowledge base. Finally, once negotiated and correct there is a sense in which information communicated belongs to the individual, the group, and the class.

The observed use of mobile devices to record images, for example from whiteboards/walls, projected images or experiments in process, introduces a new dimension to communication of science, going beyond the classroom laboratory. It increases the potential number of connections that can be made, and provides access to group resources that have gone unseen and/or been under utilised in the past. It extends the life of texts (e.g. whiteboarding/walling) and images (projected) that have specific personal resonance. These mobile images are a record of the individual student's lived experience of learning and become shared resources across the group (Nyiri, 2002; Roschelle, 2003; Seitzenger, 2014; Valk et al., 2010). Thus learning objects that have a life beyond the formal learning environment may become effective tools for communication of science, extending well beyond formal learning activities.

Allocation, as well as optimal placement of physical and digital tools and resources influences students' utilisation of these tools, and their potential for learning and for communicating enquiry and understanding. Physical and digital tools and resources are utilised to structure activities, yet activities emerge from the availability of these tools and resources. The extent of the use of technologies nonetheless needs to align with the goals of the task. For example, quite limited use of technology may be sufficient to achieve the aims of the experiment or simulation, and use of technology where it may not be required may in fact hinder student engagement and skills acquisition. For students to adequately interpret the requirements of tasks, including the intention of the task designer, they must "identify the implicit social values associated with knowledge and practices" within the learning context, including translation of cues that are communicated to them, through instruction, text or projected images etc. (Goodyear & Carvalho, 2013). Where use of cues is not aligned well with the tasks that need to be undertaken, these cues can be seen to interrupt, rather than facilitate the process of learning and communication of science. From our observations, cues that embody the instructor (e.g. real time or pre-recorded projections of practical demonstrations or instructions) or are closely aligned with the learning context, seem to produce more favourable observable outcomes in learner activity with respect to communication. That is, greater student engagement with the learning tasks, more frequent discussion of concepts and questions, and demonstration of a complex level of understanding through their ability to express their knowledge in language and through practices is observed. Thus quality of interaction is improved by the appropriate use of cues and tools available to facilitate communication. These cues and tools are important, but are not well utilised if they are not paired with the objects of communication (e.g. experimental equipment, computer simulations, ideas and enquiry) and quality of instruction.

Prior studies of learning spaces have found that flexible, collaborative, and technology-enhanced learning spaces increase interaction and engagement between students in tandem by enabling diverse learning activities and interpersonal interactions (Hunley & Schaller, 2009; Wilson & Randall, 2012). Such spaces increase options for choice of teaching and learning strategies and prompt or encourage curriculum innovation (Hunley & Schaller, 2009; Wilson & Randall, 2012). Collaborative learning spaces that increase transparency of learning and teaching enable students (and instructors) to learn from each other and from each other's successes and failures (Brown, 2006; Wilson, 1994; Wilson & Randall, 2012). The observations described in the current exploration corroborate findings from prior studies and point to means by which the science undergraduate educational environment can be optimised for engaging with and communicating science. Research- and technology-enhanced learning spaces optimised for learning the 'how' of science permit designers of curriculum and instructors to utilise task, physical and social design elements to engender scientific enquiry, culture and practice in students, hence facilitating science communication in practice. These spaces appear to increase the sense of agency in students. Unencumbered by resource limitations, they are able to explore and engage in a scaffolded manner, utilising tools and equipment that facilitate and provide the objects of communication of their science. In these spaces students are enculturated through "peripheral participation…engaged in real work" to become part of a "community of practice…[moving] from the periphery to a more central position in the community" (Brown, 2006). Spaces that increase agency enable students to become more active participants in their learning, co-configuring their environment to facilitate their understanding and communication of the knowledge and competencies they are developing, and co-creating their learning through exploration, experimentation and communication.

The current investigation takes as its method ethnographic observation, appropriate for an exploratory analysis such as that described here. To more fully explore how aspects of physical, task and social design impede or facilitate communication of enquiry and development of science communication skills *in situ*, we must triangulate our observations with interview and questionnaire data. Nonetheless, ethnographic observation has provided a means by which we have been able to identify and relate a number of elements in the learning environment, including physical, digital, individual and social, in an analysis that matches the complexity of the learning and the environment in which it is occurring (Goodyear & Carvalho, 2013). Interviews will offer student perceptions and experiences in the learning spaces and the position of the spaces in supporting and enhancing learning of skills such as communication skills. Further, questionnaires will contribute quantifiable data on the extent to which specific physical and technological, social and task aspects of learning and teaching influence participation in learning activities in the spaces. Future studies need to address linkage of learning space 'performance' and the 'goals' of learning spaces to student learning outcomes (Dugdale, 2009), including measurable gains in science communication skills. Nonetheless, learning outcomes are dependent on a significant number of variables within and beyond the learning space (Powell, 2009), making assessment of specific learning outcomes complex (Hunley & Schaller, 2009). Thus, observation of behaviours and activities relevant to learning outcomes (Hunley & Schaller, 2009; Powell, 2009) and competencies is an important first step.

Many educational design projects which are focused on mastering discipline content, disciplinary practices and transferrable skills are located at what Goodyear and Carvalho (2013) refer to as the "meso" level: the level of the learning tasks, utilising existing spaces, resources and networks. Rarely is educational design focused at the "macro" level, of replanning a campus or introducing a new model of education into a campus's education fabric. Design that is focused at the macro-level can have a powerful influence on what happens at the meso- and micro-levels, as demonstrated here through the deliberate design of new research-enhanced, technology-enabled, flexible and collaborative, transdisciplinary learning spaces. Design of space from the perspective of how it is used optimises learning of the knowledge, competencies and transferrable skills the spaces were intended to foster.

In conclusion, our analysis has suggested that elements of learning spaces where students 'learn by doing' science influence student engagement and quality of instruction, in turn enhancing communication of enquiry and conceptual understanding during task performance. Where learning spaces are designed (or redesigned) to promote communication of science and development of communication skills, task and social redesign may well also be needed. Gaining a firmer understanding of their interdependences, and quantifying the scale of effects, will provide the motivation for the next phase of our research.

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