A case study in online formal/informal learning: was it collaborative or cooperative learning?

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Abstract: Developing skills in communication and collaboration is essential in modern design education, in order to prepare students for the realities of design practice, where projects involve multidisciplinary teams, often working remotely. This paper presents a learning activity that focusses on developing communication and collaboration skills of undergraduate design students working remotely and vocational learners based in a community makerspace. Participants were drawn from these formal and informal educational settings and engaged in a design-make project framed in the context of distributed manufacturing. They were given designer or maker roles and worked at distance from each other, communicating using asynchronous online tools. Analysis of the collected data has identified a diversity of working practice across the participants, and highlighted the difficulties that result from getting students to work collaboratively, when not collocated. This paper presents and analysis of participants' communications, with a view to identify whether they were learning collaboratively, or cooperatively. It was found that engaging participants in joint problem solving is not enough to facilitate collaboration. Instead effective collaboration depends on symmetry within the roles of participants and willingness to share expertise through dialogue. Designing learning activities to overcome the challenges that these factors raise is a difficult task, and the research reported here provides some valuable insight.

Keywords: design education, makerspace, collaborative learning, cooperative learning, formal and informal learning

1. Introduction

Design is social, involving multidisciplinary teams working together, often remotely, to understand and identify solutions to real world problems (Cross and Cross, 1995). Design outcomes are reached through argumentation and negotiation (Bucciarelli, 1994; Henderson, 1999), and designers have to collaborate and communicate with a diverse range of actors who may have an interest in the design process, from managers, to members of the public, from marketers to makers (Chiu, 2002). But this is a potential barrier to design success because of a wide range of issues, including differences in culture, language, process, and location (Vandevelde and Van Dierdonck, 2003). An education in design should prepare students for these difficulties and equip them with the necessary skills to work effectively within multidisciplinary teams. However, design education often offers limited exposure to the necessity of effective communication and collaboration, because student projects are, on the whole, contained within the comfortable context of a design studio (Kuhn, 2001). Exposure to external agents is limited because design students often implement all aspects of a project themselves, from ideation to prototyping, and they carry out their design processes alongside their peers, supported by their tutors. As a result, concepts and ideas can be shared using common language familiar to the studio inhabitants (Boling and Smith, 2013). This is very different from the realities of an authentic design process.

In this paper, a learning activity is presented in which undergraduate students, studying for a design qualification with the Open University[1], an innovative centre for distance learning in the UK, undertook a design-make project in collaboration with vocational learners based in MAKLab[2], a community makerspace in Glasgow. In the activity, participants engaged in an authentic learning experience (Stein et al. 2004), that replicated a real-world distributed designer-maker relationship, and bridged formal and informal learning. Participants from the Open University and MAKLab worked as designer-maker pairs, to develop chair designs via reflection on physical prototypes. The aim was for participants to learn from each other, so that the vocational learners at MAKLab could develop conceptual and theoretical understanding of the design process, while the Open University design students could engage with the making process and the realities of production.

This paper presents results that explores the extent to which participants in the learning activity engaged in collaborative or cooperative learning. Communications of the participants were analysed to identify patterns that are indicative of these different modes of learning. It was found that engaging participants in joint problem solving is not enough to facilitate collaboration. Instead effective collaboration depends on symmetry within the roles of participants and willingness to share expertise through dialogue. Designing learning activities to overcome the challenges that these factors raise is a difficult task, and the research reported here provides some valuable insight.

2. Bridging formal and informal learning in design and making

MAKLab is an innovative Scottish charity focused on providing resources for people from all backgrounds, of all ages and all abilities to use physical making as a tool for social empowerment, regeneration, economic growth and social capital. It was founded in 2012 to allow people access the latest disruptive technologies but since then has grown to a network of spaces that deliver teaching workshops, community outreach programmes, professional development and accredited learning for a wide demographic across Scotland. MAKLab are committed to developing innovative teaching environments that are responsive to the future needs of design and manufacturing and they are investigating teaching scenarios that equip designers and makers for the challenges of the future.

Makerspaces, such as MAKLab, offer novel informal environments for training in networked, distributed, yet localised environments. They offer a locus for training programmes that bridge educational needs of differing students and enhance both technical expertise and ‘soft skills’, including problem solving, communication and collaborative working (Halverson and Sheridan, 2014). But, informal education of this type can be too instrumental, because methods and skills are learned in specific situations, with little consideration of underlying concepts and theory (Resnick, 1987). As a result learners may have difficulty applying learned methods in new situations.

MAKLab are interested in identifying how to generalise their educational offering, and one approach identified is to offer longer projects that have practical real-world applications. Existing programmes, such as the MIT led FabAcademy[3], have identified a role that higher education (HE) providers can play in supporting makerspace based learning. This programme follows a distributed model where tutors are trained and teaching material is produced centrally, but learning takes place remotely, within independent makerspaces distributed globally. In the learning activity presented in this paper we explore an alternative model of makerspace based learning which involves equal investment and reward for the HE provider and the makerspace, with students from the formal HE context

[1] http://www.open.ac.uk/
[2] http://maklab.co.uk/
[3] http://fabacademy.org/

benefiting from the learning that takes place in the informal context of the makerspace, and vice-versa. In this particular scenario the makerspace is MAKLab and the HE provider is the Open University.

The Open University has been a centre for distance design education since the 1970s, and stands apart in its approach to teaching about design and design processes instead of teaching how to design (Lloyd, 2013). This pedagogical approach was adopted partially due to the difficulties involved in providing authentic practical experience for design students studying at a distance. Only recently with the introduction of online technologies, such as Open Design Studio (Lotz et al., 2015), has a studio-based learning environment been possible for design students studying at a distance. But, providing access to tangible aspects of a design education, such as making and prototype building, is still difficult because students typically do not have access to the tools, materials and expertise, that are available in traditional design studios, and online activities cannot act as a replacement. Despite, this design education at the Open University is typical of higher education learning in that it focuses on developing broad skills and understanding of theoretical principles. This is a direct contrast to the instrumental learning that takes place in makerspaces, and rarely does HE education map directly onto the knowledge that people use in work situations, even those learned through highly technical professional training (Garner, 2005; Resnick, 1987). This paper describes a learning activity undertaken as a partnership between the OU and MAKLab that seeks to bridge formal and informal learning, with the intention that HE providers and makerspaces can benefit from each other's strengths while negating limitations in learning provision.

3. A collaborative design-make project

3.1 Background

The learning activity was developed with reference to a study reported by Prats and Garner (2009) in which design students at the Open University were given an opportunity to engage with the making process, in order to augment and enhance their studies. In that research, the focus was on the role of making in design education, expanding on McCullough's (1998) premise that design students studying via a distance learning approach must be able to engage with physical models as well as with digital tools and outputs. Participants were tasked with designing a children's chair, to be manufactured out of 15mm MDF, and the study took place over several iterations of a design-make-analyse-reflect cycle, replicating a typical design process while drawing strong parallels with the Kolb cycle of experiential learning (Kolb and Fry, 1975). Technical and design support was provided at a distance and the participants' rough sketches of chair designs were converted into plywood fifth-scale models which were then mailed back to them, for analysis and reflection. The study confirmed that giving students access to physical models is vital for supporting design education at a distance because they assist in the act of reflecting about form and shape. It also confirmed that distance learners need not be deprived of this important aspect of their education, but that the design-make cycle can be incorporated in their design processes. However, some weakness were identified in the pedagogical model used, the most apparent of these being the work-overhead for the technician who had responsibility for converting drawings into models, and this often involved lengthy communication with students in order to elicit design intention.

In the learning activity reported here we adapted this model by including vocational learners located at MAKLab, who not only took on this role of technician, but were also given additional authority with the extended role of 'maker'. Participants were briefed, to emphasise that we expected equal participation and agency from designers and makers, rather than the prior model of a technician acting as a service provider to the 'designer'. It was anticipated that this collaborative model of learning would benefit both groups of learners by giving them a real-world project that enabled them

to develop necessary technical skills, and also by encouraging them to collaborate within a distributed network by communicating asynchronously, using online technology.

3.2 Participants

Sixteen participants were drawn from the Open University and MAKLab, two distinct educational settings. The eight Open University participants had recently completed a second-level design module, which focussed on developing essential designs skills, and the eight MAKLab participants were vocational learners interested in developing their making skills using MAKLab facilities. The project attracted a diverse group, with a wide range of experiences, education, and backgrounds, and this diversity was apparent in both settings.

The Open University participants (who will be referred to as the designers) were selected from a pool of applicants who responded to a call to participate. This was circulated to students who had recently completed the second level design module "T217: Design Essentials". No remuneration was offered, but applicants were told they would be allowed to keep the prototypes they produced during the project. The designers were all studying at a distance, distributed around the UK, and one was based in Germany. Six of the designers were registered on a design-based qualification, e.g. BA/BSc (Hons) in Design and Innovation, while the remaining two were working towards a general Open Degree. Their experience of design and making outside of their studies varied, ranging from no experience at all, to practicing designers e.g. in jewellery, and 3D modelling. For most, their primary motivation for participating was to enhance their learning, by engaging in making activities that are difficult to support in distance education. A popular secondary motivation was to experience collaborative working on an authentic design project. All of the designers engaged with the project from their own remote locations, and it took place over the summer study-break, to minimise the impact on their formal learning, whilst also providing a bridge between successive periods of study.

The MAKLab participants (who will be referred to as the makers) were selected from a pool of applicants who responded to a call to participate. This was circulated via MAKLab mailing lists, and advertised at MAKLab locations. No remuneration was offered, but participants were offered their choice of prototype chair on completion, and given membership of MAKLab, which also ensured compliance with health and safety requirements. The participants were all based in or around Glasgow, Scotland, and all of the making activities took place at a MAKLab facility in Glasgow. Two of the makers were already members and volunteers at MAKLab, but the other six had never previously used MAKLab services. Some had prior design experience and/or prior making experience using traditional tools and techniques, but none of the makers had prior experience working with the manufacturing tools used in this project. Two were graduates, in aerospace engineering and media technology; two were employed, in the IT industry and electronics engineering, the others were self-employed, e.g. as artists or designers, were volunteering or were unemployed. For most, the motivation for participating in the project was around career development, including learning new skills, developing their portfolio for future job applications and for the employed/self-employed individuals, using the opportunity for Continuing Professional Development training.

3.3 Task

Participants were randomly allocated partners to form designer-maker pairs, and within their pairs they were tasked with designing a chair that could be economically manufactured and transported. The brief specified that the chairs needed to

- accommodate adults
- be designed for ease of assembly, with no adhesive or fixings
- be manufacturable using a CNC router
- be flat-packed for ease of transportation

- be manufactured from a single material, specifically 12mm thick plywood
- minimise waste created during manufacture

This brief was composed with reference to the earlier study reported by Prats and Garner (2009), where chair design was chosen as the context because it was explored in the second level design module the students had recently studied. Despite their simplicity, the design of chairs is an interesting problem that attracts many world-famous designers, e.g. Toromanoff (2016). For this project, it was a useful scenario to encourage design students to engage with the challenges of design for assembly. MAKLab identified CNC (computer numerical control) routers as an appropriately flexible technology, with scope for learners to develop industry-relevant skills and expertise. The other requirements were identified with the intention to constrain the design process, and to ensure the project was authentic, by focussing on human needs and production realities (Morgan, 2012). It was anticipated that the resulting project would be a collaboration between designers and makers, with both developing skills and knowledge, as they worked together in a manner that mimicked a real-world scenario of distributed manufacturing.

3.4 Schedule

The twelve week project involved three design-make cycles, as illustrated in Figure 1. In the first cycle, the designers were given the brief and asked to respond to it by conducting appropriate research and exploring initial ideas and concepts. In the third week, makers attended a CNC training course, during which they were introduced to the technology, and were given an opportunity to cut sample furniture. After the makers completed the course, the designer-maker pairs were introduced to each other, via the online forum, and started working together on the project. Designers were encouraged to start communicating their ideas and their research to the makers. Similarly, makers were encouraged to share their understanding of the CNC process, in order to help shape initial concepts according to their feasibility. During the fifth week, the first making session began, where makers were given access to MAKLab's CNC routers in order to fabricate the initial chair designs. These were then shipped to the designers, flat-packed. In the second cycle, designers were given an opportunity to reflect on their designs, and together with the makers, identify opportunities for improvement. During the eighth week, the second making session began, and the modified chair designs were again shipped to the designers. The third cycle, replicated the second, with a third making session taking place during the twelfth week, and designers received their final prototypes soon after.

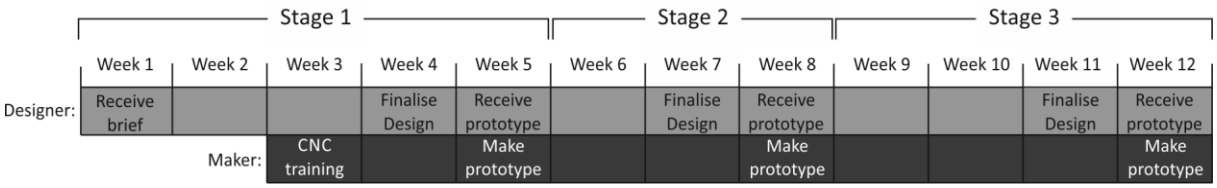

Figure 1. Timeline of the project

Designers were encouraged to use Sketchup[4], a free to use 3D modelling software, to construct digital models of their designs, and to export these as 2D dxf files, for input to the CNC routers. To support the participants, one Open University-based staff member was assigned the role of design-tutor, and one MAKLab-based staff member was assigned the role of maker-tutor. A hands-off approach to tutoring support was encouraged, and tutors intervened only when issues were identified that limited the progress of the participants, e.g. technical issues around constructing and exporting 3D digital models as 2D dxf files. Health and safety considerations necessitated that the

[4] http://www.sketchup.com/

maker-tutor played a more hands-on role supporting maker participants in the production processes than the designer-tutor with their cohort.

3.5 Data collection

A variety of methods were used to record all aspects of the learning activity. The primary method was an online forum that participants were encouraged to use to communicate with each other and with the project team. Open Design Studio was not available for this project, and instead a bespoke text-based forum was built. Forums have limitations as methods of communication, being impersonal, asynchronous and text-based; but they also have significant strengths, because they can be accessed at any time and place, their asynchronous nature encourages more reflective and considerate dialogue, and a record of conversations is kept and can be revisited (Ellis, 2001). It has also been recognised that asynchronous communication can hinder collaboration (Dillenbourg, 1999). But, for the purposes of this research, forums were deemed appropriate to replicate the real-world asynchronous communication that often takes place between distributed designers and makers. In that context, asynchronous communication plays an important role in creating a permanent and auditable record of decision making, which can be useful for avoiding conflict and misunderstanding. This record of conversations was also identified as an important benefit for the research project itself, because it resulted in a rich data source which could be used to analyse the participant's communications.

Participants were given access to three project level forums, Information, FAQ, and Discussion forums, which were accessible to all participants, as well as the tutors and other Open University and MAKLab staff members, who acted as forum moderators. Each designer-maker pair was also allocated a Chat forum, with which to communicate to each other on an individual basis. Each Chat forum was accessible only to the allocated designer-maker pair, the tutors and the moderators. Designers were allocated a Design Blog, which they were encouraged to use to record their own thoughts and design process. These were private to the individual designers. In parallel to this, makers were encouraged to keep work-books, to replicate a typical vocational learning process.

In addition to the forums, designers completed surveys at critical stages of the project, in order to record their views on their progress, their communication with their partners, and reflections on their design process. These were circulated prior to designers commencing the project, and at the end of each design-make cycle. Also, at the end of the project designers were interviewed by telephone. The makers were interviewed, face-to-face, prior to the start of the project, and at the end of the project.

3.6 Summary of Results

Seven of the designer-maker pairs completed the project, and a total of 18 full-size prototype chairs were made and posted to the OU design students. These are presented in Figure 2. Participants' journeys through the process were all unique, and each had their own story to tell of their experience, and these were generally all positive. From the collected data it was apparent that, as a result of the process, participants developed technical skills in designing and making; they learned new approaches to communication; and they recognised the difficulties inherent in distributed manufacturing that result from working remotely. The designers also benefited from engaging with material aspects of their design process, reinforcing the findings of Prats and Garner (2009). Evidence for these claims were captured in the conversations on the forum, and in the surveys and interviews, and illustrative examples of this evidence is provided in Table 1. In the remainder of this paper, the focus is on the posts uploaded to the Chat forums with an aim to understand how the participants communicated as they worked together to address the design brief.

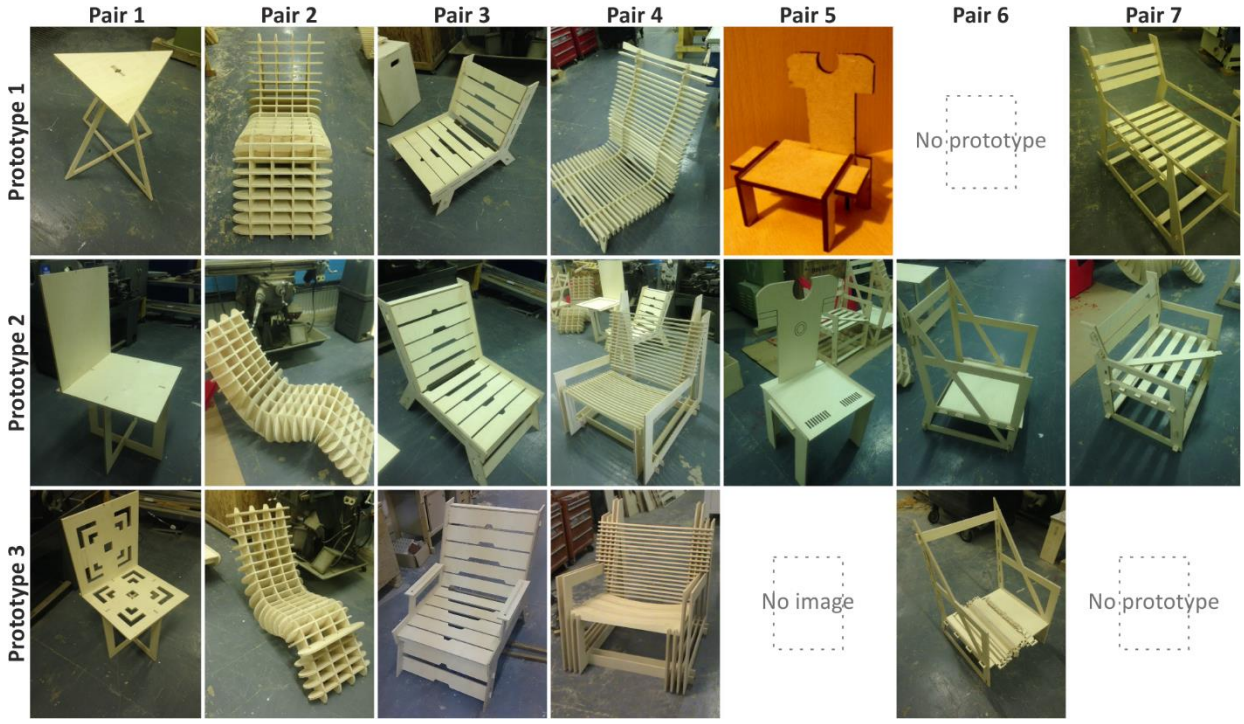

Figure 2. Prototype chairs produced by the participants

Table 1. Evidence of learning

Learning identified	**Evidence of learning**
Technical skills	*"I actually tried to avoid Sketchup [during the preceding OU course] … Now I am so confident in it I am actually applying for a job as an interior designer where they are asking for Sketchup"*
Communication skills	*"getting that [design] into a 'language' that the manufacturer can understand and can work with is an issue that needs to be addressed and overcome"*
Difficulties of distributed manufacturing	*"the project has given me a great insight into what it is like working with someone remotely"* *"words are a horrible way to communicate design concepts"*
Importance of materiality	*"seeing the actual chair helped me to realise how it really presents itself and adjust its dimensions"*
Design process	*"I think it is important to make mistakes in order to learn from them, for me that is what design is all about"*

4. Designing and making chairs at a distance

During the activity there was a wide diversity of working practice across the participants, with designer-maker pairs working and communicating in a range of different ways. For the purpose of illustration, we have identified three designer-maker pairs that highlight this diversity:

- Pair 2, where due to technical issues the maker was limited in his engagement
- Pair 4, where both maker and designer were very engaged
- Pair 5, where the designer struggled with the materiality of the design

4.1 Designer-maker pair 2

In designer-maker pair 2, the designer (Designer-2) had some prior design experience having completed an internship which involved designing and building structures for a sustainable urban farm. The maker (Maker-2) was a self-employed digital artist who had experience in community building projects. Designer-2 shared early sketches and design ideas (illustrated in Figure 3), and requested feedback about their feasibility with respect to CNC. She also uploaded photos of a paper-model to illustrate the intent behind the design concept. Unfortunately, Maker-2 had limited internet access, and his responses were sporadic and brief; he gave little input into the first design concept, only positive encouragement and instructions on how to present parts in the CAD file. Consequently, when Designer-2 received the first prototype, she was surprised that the geometry was different to the CAD model, due to CNC toolpaths not accurately reproducing the curves of the chair design. Designer-2 become frustrated because she perceived this as a consequence of the lack of communication from Maker-2.

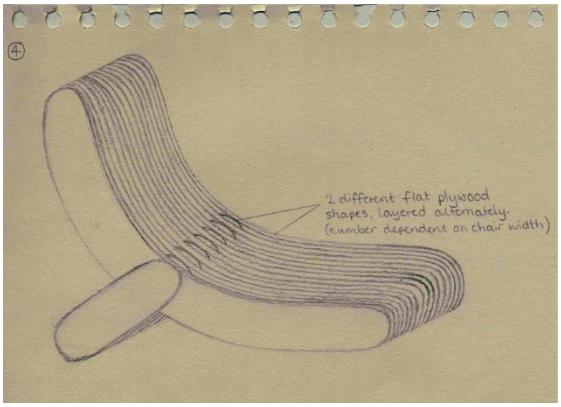

Figure 3. Initial chair sketch produced by Designer-2

On reflection of the first prototype, Designer-2 developed the concept further by adapting the geometry of the chair. Having the physical artefact gave better insight into the required dimensions of the chair, and informed evolution of the concept. Again, design input from the maker was limited, however there was more communication about the manufacturing process. In the second prototype, the basic concept remained the same, but the back and leg rests had been extended to allow for better support. Unfortunately these modifications meant that the design could no longer be assembled. For the third prototype she attempted to develop her understanding of the making and assembly process in order to address this issue, but with only limited input from Maker-2.

4.2 Designer-maker pair 4

In designer-maker pair 4, the designer (Designer-4) had significant previous design experience in jewellery design, furniture design, set building and 3D modelling. The maker (Maker-4) had some making experience, and was a volunteer at MAKLab. Communication was initiated by sharing personal information, including photos, to establish a relationship. The design brief was addressed by first exploring the problem and its constraints. The CNC process was discussed, Maker-4 shared some existing chair designs, as well as examples of the types of joints that could be used (illustrated in Figure 4). The pair also discussed the best way to communicate design intent using coloured lines, and identified an appropriate colour-scheme. Designer-4 shared six potential concepts, as rendered 3D models, and requested that Maker-4 help choose the most appropriate for the project, based on requirements of comfort and the project constraints. Design files were

uploaded early to give Maker-4 time to assess their suitability for making, and Maker-4 shared photos of the making process.

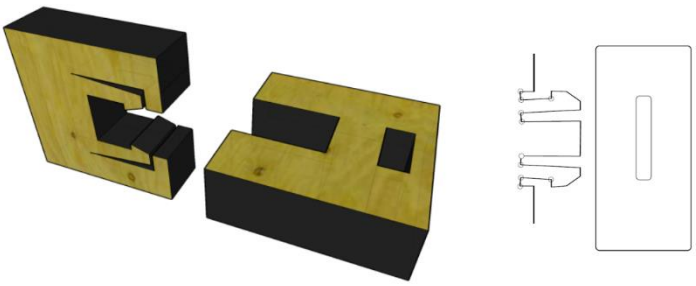

Figure 4. Examples of joints produced by Maker-4

The first prototype broke when Designer-4 sat on it, and in response the chair was redesigned to ensure a stable structure. The second design-make cycle followed a similar process of exploring the problem to establish constraints and opportunities for improvement. Alternative methods of fixing the chair were identified by both Designer-4 and Maker-4, as well as possible methods for finishing the design. Again design files were uploaded early to give enough time for discussion and identification of any issues. The third design-make cycle also followed this pattern, with designer-maker pair discussing all aspects of the project, the design and the making process. Maker-4 decided to modify the design during the third making process and identified design errors to justify these decisions. Designer-4 was initially upset about the changes but eventually conceded that there was an error in the design files.

4.3 Designer-maker pair 5

In designer-maker pair 5, the designer (Designer-5) worked in banking and had no previous design experience. The maker (Maker-5) was an artist, specialising in replica props and costumes, and had varied making experience, but had never used a CNC router before. Designer-5 started the process by referring to an exercise on chair design that was part of his second level design studies, and from this produced sketches exploring a chair with a t-shirt motif. After some experimentation, he converted some of these to 3D model in Sketchup. As Designer-5 became more fluent using the software, the models increased in sophistication and gave a good indication of the design intent, but there was no consideration of assembly – instead chairs were presented as solid monoliths, with no obvious parts, as illustrated in Figure 5. Maker-5 joined the process after the 3D models had been uploaded and responded to these by discussing the making process and highlighting the requirements of the brief. He emphasised the need to identify the parts of the chair so that these could be cut from a sheet of plywood using CNC, and directed Designer-5 to information about how to create joints. Designer-5 struggled to understand how to re-present his designs in the correct format so that the parts were identified and joints included. He also struggled to implement advice regarding the dimensions of his design.

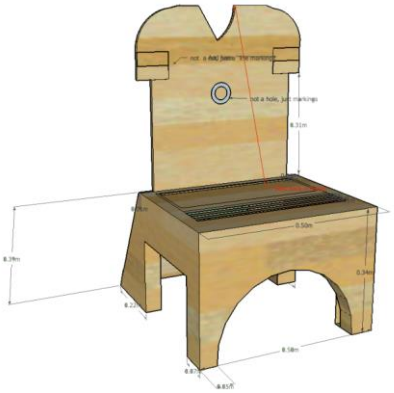

Figure 5. Example of CAD model produced by Designer-5

Despite efforts to try and resolve these misunderstanding, and some guidance from tutors, the required design files were not ready on time, and the first prototype was not built. Instead, Designer-5 was sent a quarter-scale model, cut out of 3mm plywood on a laser-cutter. This model helped him understand the advice of Maker-5 and the tutors, because it made apparent the errors in the design. With the physical model in hand, Designer-5 was able to improve his design files over the course of the second design-make cycle, so that a full size prototype could be made. From this, Maker-5 was able to identify further design faults, and other opportunities for improving the design, such as using alternative joints. Designer-5 was able to correct the simpler modifications, but was unable to implement the more significant changes, and the result of the third design-make cycle was an improved, but flawed chair.

5. Collaborative or cooperative learning?

5.1 Definitions of collaborative and cooperative learning

The learning activity presented in this paper has been described throughout as an example of *collaborative learning*. This refers to the fact that participants were involved in joint problem solving, a common activity in the traditional design studio (Boling and Smith, 2013), and aligns with the definition given by Rochelle and Teasley (1995; p70), which states that

"Collaboration is a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem"

Dillenbourg (1999) expands on this definition and explores different elements of a collaborative learning activity, including situation and interaction. A *situation* is collaborative if there is symmetry in the roles of the participants, if they have a common goal, and if they work together to meet this goal, while *interaction* is collaborative if there is opportunity for negotiation and misunderstanding (Dillenbourg, 1999). The learning activity presented here was designed to meet both these criteria. The pairing of participants was symmetrical in terms of knowledge and status – each pair consisted of two learners of a particular discipline (design or making) and was assumed to have sufficient expertise in that discipline to act with authority. They had a common goal of designing and making a chair to meet the given brief, and they had to work together to meet this goal, because both roles (designing and making) were essential and each had incomplete knowledge of the other's domain. There were opportunities for negotiation about the design and its realisation; and there was opportunity for misunderstanding, about expectations and intent. This is evident in the interactions of pair 4 and pair 5, as described in the previous section. Despite this, not all participants collaborated to the same extent, and it could be argued that some cooperated instead.

Panitz (1999) defines cooperation as a *structure of interaction* where participants have to work together in groups to meet a specific goal, and is differentiated from collaboration which is defined as a *philosophy of interaction* where participants are responsible for their own actions and respect the abilities and contributions of others. Both types of learning activities involve participants working together to meet a goal, with different participants having their respective tasks to complete; the difference is in ownership and authority. In a cooperative activity, authority remains with a tutor, who retains ownership of the task and defines a set of processes for the student participants to follow, but in a collaborative task, the authority is transferred to participants, and successful collaboration requires them to take ownership, to negotiate roles, and to define their own processes. Bruffee (1995) suggests that the extent to which participants can own a collaborative task depends on their level of sophistication. For students who are developing their foundational knowledge of a subject, cooperative learning is more appropriate because they have not yet developed the necessary level of sophistication. To engage in collaborative learning students need to engage with non-foundational knowledge which results from reasoning and questioning; they need to negotiate and

expand the boundaries of their knowledge, in order to negotiate and respond to the needs and requirements of other participants. This requires a certain mastery of a discipline and if, in a team of collaborators, some participants do not possess this mastery then an imbalance can arise, which can result in a shift in roles (Dillenbourg, 1999).

5.2 Analysing participants' communications

The extent to which the learning activity described in this paper was collaborative, in terms of situation and interaction, can be explored by considering the communications made between designer-maker pairs, as recorded in the asynchronous Chat forums. The number of posts on the forums are summarised in Table 2, and these numbers indicate that that some participants communicated more frequently than others. In pairs 2, 3, and 5 the designer communicated more frequently than the maker, possibly suggesting a lack of engagement from their partnering makers. Pair 4 stand out due to their large number of communications, and Pair 7 is unique as the only pair where the maker communicated more frequently than the designer.

Table 2. Summary of designer-maker communications

	Designer Posts	**Maker Posts**	**Total**
Pair 1	20	19	39
Pair 2	51	21	72
Pair 3	40	28	68
Pair 4	126	124	250
Pair 5	69	19	88
Pair 6	26	19	45
Pair 7	37	41	78

It was anticipated that the scenario of distributed manufacturing would result in designer-maker pairs collaborating as equals, with each sharing and learning from the others' experience and expertise, but the raw numbers in Table 2 give little insight into the extent to which this occurred. Further analysis of the communications recorded on the forums provides insight into the extent to which the participants actually owned their roles as designer or maker, and the extent to which they expanded their boundaries of learning. This analysis is presented in Figure 6.

Participants' posts to the forums were categorised according to who posted them, designer or maker, and according to their content. Content was categorised according to *Design Issues*, *Making Issues*, or *Other Issues*. *Design Issues* included any discussion of the design of the chair, such as inspiration for the design and design intent, aesthetics, structure, joints, design for assembly, etc. For example, the following post gives advice about how to modify a design to improve its structure: *"the back panel has legs and an arch feature but the front is just left open, have you considered putting a similar panel on the front?… it would add more rigidity."* Also included were any posts where design files were uploaded, such as sketches, photos of models or 3D models. Such files were an essential means for communicating design ideas and design intent, and were required by the maker for the manufacturing process.

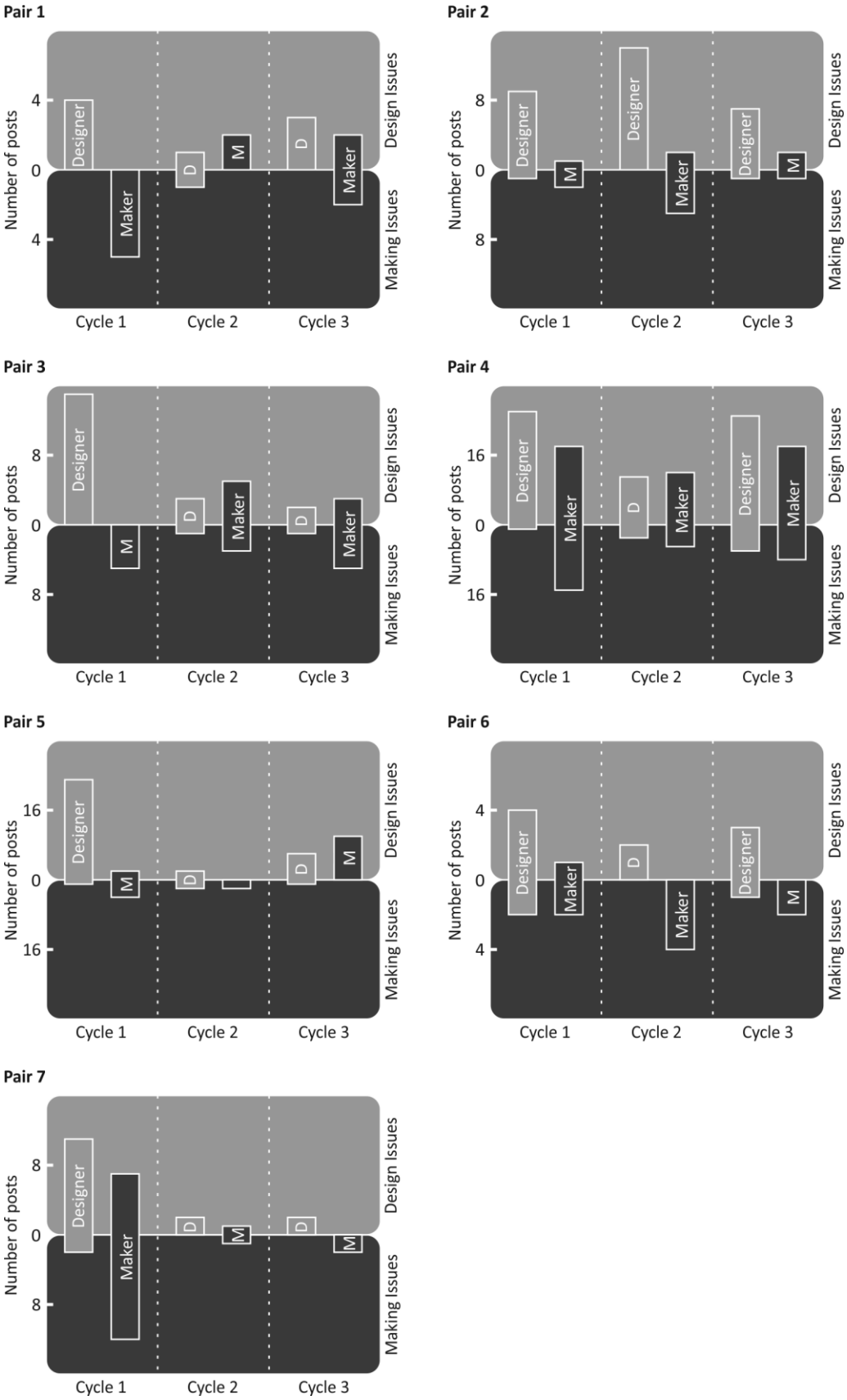

Figure 6. A visual summary of communications between designer-maker pairs, according to the number of posts referring to design and making issues in the three different design-make cycles.

Making Issues were any discussion of the making of the chair, including descriptions of the making process, the capabilities of the CNC router and any resulting constraints on the design. For example, the following post gives advice about how the making process limits the design of a chair: *"The only problem I see is with the arm rests. I like the design but we would struggle to make the wings."* Also included were any photos of the making process and subsequent assembly of the prototype chairs. These were essential for giving designers insight into how the chairs were being produced and the reasons for constraints imposed by the makers, and they informed designers' reflections on how to improve their designs.

Posts discussing *Other Issues* were not included in the analysis. These included posts where participants built relationships by sharing personal information; posts discussing the structure of the project, such as timings for uploading design files and for making prototypes; posts discussing technical issues, such as errors in design files, or failure to present the design in the correct format. Also, posts merely acknowledging participants feedback or comments were not included.

The graphs in Figure 6 are a visual summary of the interactions of participants on the forums, and represent the number of posts referring to design and making issues, according to who posted them and in which design-make cycle. Note that not all the graphs are on the same scale, but for the sake of this analysis it is the relative number of posts between designer and maker in a pair that is of interest. In these graphs we can identify patterns of communications between the designer-maker pairs, which gives insight into how they communicated, which in turn is an indication of whether a pair was collaborating or cooperating. In response to the definitions of collaboration and cooperation given by Dillenbourg (1999) and Panitz (1999), we are interested in identifying the extent to which the designer-maker pairs shared the goal of designing and making a chair, and also in the symmetry of their roles. The project was framed so that ownership of the design was held by the designer, whilst ownership of the making process was held by the maker. In a successful collaborative process, we would expect evidence of sharing across these boundaries, in order to develop mutual understanding and a common goal (Kotlarsky and Oshri, 2005).

In the graphs, three particular patterns are of interest, and these are illustrated in Figure 7. In Figure 7a, the designer is creating the majority of post about design issues and the maker is making the majority of posts about making issues; the designer and maker each retain full ownership of their expertise. This indicates that for each participant, their focus is confined to their respective discipline; they are working together but there is little evidence to suggest they are negotiating or extending the boundaries of their knowledge according to the input of their partner. According to the definitions given by Dillenbourg (1999) and Panitz (1999) the pair are working *cooperatively*. In Figure 7b, designer and maker both create a similar number of posts about design and making issues; both are engaged significantly in design and making aspects of the project. This indicates that the pair are working together and are extending the boundaries of their knowledge by negotiating every aspect of the project. According to the definitions given by Dillenbourg (1999) and Panitz (1999) they are working *collaboratively* to meet a shared goal. In Figure 7c, the maker is creating the majority of the posts about both design and making issues; the maker is taking ownership and authority of the project. This indicates an asymmetry in the working relationship, which according to Dillenbourg (1999) can result from the designers' lack of mastery of their discipline.

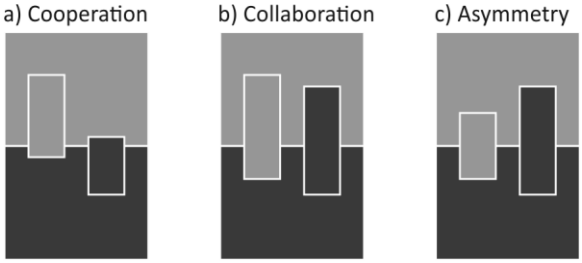

Figure 7. Key patterns indicating types of interaction

These three patterns account for all the communications of all the pairs as recorded in Figure 6. A colour coded summary of these communications are summarised in Table 3, to highlight the different patterns. For example, for Pair 2, in all three cycles the pattern is similar to that in Figure 7a, indicating that pair did not truly collaborate over the course of the project. This reflects the narrative presented in the previous section: the maker had limited access to the internet and consequently was unable to fully engage with the project. As a result, without the maker's input, the chair design developed little over the three cycles, as seen in Figure 2. For Pair 4, the dominant pattern in all three cycles is that of Figure 7b, with both participants extending their knowledge to the others' discipline and both sharing the same goal. Again this reflects the narrative of the previous section: both designer and maker were generous with their expertise and their time. As a result, an interesting design evolved over the three cycles through collaborative dialogue about the problem, the design, and the making process, as seen in Figure 2. Pair 5 have a combination of patterns: in the first and second cycle it is a pattern of cooperation; and in the final cycle, it is a pattern of asymmetry. The narrative of the previous section highlighted Designer-5's lack of mastery of the design aspects of the project, he struggled with creating design files in the correct format, and he struggled with understanding how to design for assembly. As a result he had to look to the maker for additional support, resulting in a change of the role of the maker, who took on some authority of the design role, providing in depth guidance and instruction, and essentially acting as a tutor rather than a collaborator.

Table 3. Summarising the patterns of interaction in Figure 6

	Cycle 1	**Cycle 2**	**Cycle 3**
Pair 1	Cooperation	Asymmetry	Collaboration
Pair 2	Cooperation	Cooperation	Cooperation
Pair 3	Cooperation	Asymmetry	Asymmetry
Pair 4	Collaboration	Collaboration	Collaboration
Pair 5	Cooperation	Cooperation	Asymmetry
Pair 6	Collaboration	Cooperation	Cooperation
Pair 7	Collaboration	Cooperation	Cooperation

Other pairs had different combinations of interactions. For example in pair 6 and pair 7, the pattern of the first cycle is that of collaboration, but in subsequent stages the pattern is of cooperation. In both cases this was as a result of technical issues that limited communication. For pair 3 the pattern of the second and third cycle is of asymmetry, and this is due to the designer distancing herself from the process due to personal issues. Out of all the pairs only pair 4 shows signs of collaboration,

across all three cycles. Possibly this is because they made the most effort to build a strong relationship from the start of the project. This is reflected in the type of posts they made to the forums, out of 250 posts, 111 discussed design issues and 38 discussed making issues. The remaining 101 posts discussed other issues, including project issues and sharing personal information that helped develop their relationship. It is also significant that both Designer-4 and Maker-4 were already very experienced. Designer-4 was the most experienced of the designers having previously worked in jewellery design, furniture design and set building. She was already very familiar with the tools of 3D modelling, and was aware of the need to communicate her intent with her partner as clearly as possible. Maker-4 was also experienced as a maker, and worked as a volunteer in MAKLab. Both had foundational knowledge and were relatively sophisticated in their disciplines, and this allowed them to engage with non-foundational knowledge through collaboration, confirming the findings of Bruffee (1995). None of the other design students had the necessary foundational knowledge to collaborate effectively with their maker-partners. In retrospect, this could have been anticipated because the participants were students who were still developing their knowledge of their discipline. Recognition of this issue would have made it possible to provide better support for the design students and to ensure symmetry in the roles of participants, so that effective collaboration could take place for all designer-maker pairs. But, collaboration was not essential to the learning of the participants. The collected data, including the surveys and interviews, indicate that all participants learned through the experience of working at a distance within designer-maker pairs, as illustrated in Table 1.

5.3 Reflections on the analysis

The graphs in Figure 6 show a high-level summary of the communications that took place between designer-maker pairs over the course of the project, and they concur with observations made in the previous section about the ways the pairs worked together to design and make their chairs. However, this is a very limited view, neglecting many subtleties about how the designer-maker pairs actually communicated.

In the analysis, the content of posts is reduced to a tally of their number, thereby disregarding their intrinsic differences. For example, the graph of Group 2 indicates some elements of sharing between designer and maker, with Maker-2 creating posts referring to design issues in each of the design-make cycles. But, in reality, these posts were very brief, with little content that could aid Designer-2 in the project. Conversely, Designer-2 posted infrequently about making, but some of these posts were extensive, listing questions and points of discussion, with the intention of initiating dialogue about the making process. Despite their superficial nature, the graphs are useful in indicating the patterns of interaction that the different pairs engaged in. They show that all pairs were able to cooperate (some asymmetrically) to the extent that they produced multiple chair prototypes. But, arguably, only pair 4 collaborated. Consideration of the factors that facilitated this collaboration, i.e. sophistication in their respective disciplines, and effective relationship building, should be taken into consideration when future collaborative learning activities are designed.

It is possible that the mode of communication also played a part in hindering effective collaboration. Many of the participants expressed their dissatisfaction with the forum as a tool for communication, because the asynchronous nature of the forum and the lack of notification when a post was made meant that there were often long delays between questions being asked and answered, as indicated in the following post:

"*You've gone very quiet! Are you reading my posts? I keep coming back to check. I wish that I got an email whenever anybody else posted!*"

This resulted in frustration for designers and makers, who found they had to wait for feedback or continue to work unaided. Despite this, there were also many examples of the forum working well, most notably when both parties were online at the same time and able to respond quickly to

questions and comments. This supports the findings of Dillenbourg (1999) who argues that collaboration can only occur using asynchronous online tools if the delay between messages is short enough to seem synchronous. However, more advanced approaches to digital communication, such as the Open Design Studio (Lotz et al., 2015), may overcome these difficulties, and enable learners to communicate in a more comfortable manner, e.g. replicating social media interaction.

6. Discussion

The learning activity described in this paper was designed with the expectation that the scenario of distributed manufacturing would result in designer-maker pairs collaborating as equals, with each sharing and learning from the others' experience and expertise. But, analysis of the data collected during the learning activity has shown otherwise. True collaboration according to Dillenbourg's (1999) definition was only partially reached; instead what was achieved was closer to Panitz's (1999) definition of cooperation – the participants worked together in pairs to meet a specific goal of designing and making flat-pack furniture. This finding is of significant importance to the design of collaborative learning activities. If the intended learning outcomes of an activity are to encourage collaborative working practices then providing opportunities for cooperating is not enough. Instead, learners should be grouped symmetrically and they should be encouraged to engage in dialogue, to build working relationships and to share their own expertise (Kotlarsky and Oshri, 2005).

Despite the limited amount of collaboration, the results of this activity and feedback from participants indicate that there is indeed value in giving future designers and makers the opportunity to experience an authentic remote paired working activity as part of the their training, to better prepare them for the workplace. Post-project discussions with designers and makers confirmed that the experiences of distributed design presented by the project have helped them develop technical skills, in digital and physical model making, as well develop an understanding of the complexities of communicating design ideas when working at a distance. Both groups of participants found the project to be an authentic learning experience that allowed them to apply and extend their learning in ways not previously offered within their respective learning environments. The less experienced designers, who didn't start with the base knowledge necessary to effectively collaborate did begin to develop the necessary skills as a consequence of the project. For example, Designer-5 who struggled with getting his design files into the correct format summarised his learning:

"whilst the design may be conceptually good; getting that into a 'language' that the manufacturer can understand and can work with is an issue that needs to be addressed and overcome. Collaboration is crucial"

Working together with the makers, the designers were exposed to the making process and the materiality of their designs, and through this exposure they developed their understanding of design processes. Similarly, working together with the designers exposed the makers to new methods of working and thinking, in an unfamiliar context, i.e. working online. As a result, the confidence and skills of all participants developed throughout the project. The learning activity required participants to work together remotely as designer-maker pairs, using an asynchronous online forum as their primary means of communication. Design students at the Open University have ample opportunities to communicate their work in this way, due to the distributed nature of their education. This is supported by the provision of online spaces, which host studio-like communities where students can share and discuss their work with tutors and peers (Lotz et al., 2015). But, as with a traditional university, exposure to agents external to their course of study is limited. Working with MAKLab provided the Open University students with an opportunity to communicate with agents outside the boundaries of the design studio and to collaborate with other learners. Onstenk (2013) identifies

how such collaboration can be mutually beneficial to both parties. Design students, benefit from the informal, skill focussed training that takes place in MAKLab, while the MAKLab learners benefit from communication with the designers, and exposure to the formal learning that takes place within the Open University. This type of distributed collaborative learning activity is an effective pedagogical model for extending the boundaries of traditional formal education to include informal contexts, such as community makerspaces.

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