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THE NATURE OF THE LINKS BETWEEN DESIGN AND LEARNING

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Abstract

This paper presents the nature of the links between design and learning. A design process or a learning process represents how design or learning activities are organised. An investigation into the relationships of the elements for learning and design activities was carried out to gain insights into the design and learning process. A protocol analysis approach was adopted with three experiments in two student design teams undertaken. It is found that the design activities and learning activities can be separated and intertwined, and that design activities and learning activities in different periods can be linked with each other.

Keywords: learning, design, protocol analysis, team working

1 Introduction

Design and learning have been said to be linked together with a cyclic nature [1, 2]. Learning occurs during design and what is learned can be used for current and future design practice. Recently, it was revealed that designers in a team can learn from each other through their interactions, namely collective learning, with a cyclic nature also observed [3, 4]. A design or learning process represents how different design or learning activities are organised. Although the coupled nature between design and learning was reported, how a design activity and a learning activity are linked (e.g. separated, or entwined) is still vague.

The objective of the research was to reveal the links between design and learning activities in the context of team design. A design activity can be understood as "an action or cognitive process taken by a design agent to achieve a knowledge increment in the state of the design and/or its associated design process in order to achieve some design goal" [5]. A learning activity on the other hand is a cognitive process of knowledge acquisition, during which knowledge transformation may occur [4]. A design activity can be modelled as elements of input knowledge, output knowledge, and design goal, while a learning activity can include elements of input knowledge, learning operators, learned knowledge, learning goal, and rationale trigger [3, 4]. The design goal represents the purpose to carry out a design activity, while learning goal is the purpose to learn. Rationale triggers are the reasons that trigger designers to learn. It should be noted that not all learning activities have these learning elements [4]. In collective learning, a learning operator links the input knowledge with learned knowledge and may perform knowledge transformation. It resides in the person who learns. The links between a design and learning activity were investigated, based upon an analysis of the relationships in the elements of these two types of activities.

Knowledge is defined differently by researchers in different domains, such as those in [6-8]. However, it would be difficult to find one that could be applicable to all domains. In this paper, knowledge is concerned with the nature of the design (artefact), how design activities can be organised and how the design process can be executed, adopted from [8]. It should be noted that within this work a broad view of "knowledge" is used, which includes those indicated from students' verbalisation. Indications from such verbalisations may be only propositions without tested evidence, and may indicate possible solutions and methods.

A protocol analysis approach is adopted to investigate into the nature of the links between design and learning. Cross et al. argued that protocol analysis has become "the most likely method (perhaps the only method) to bring out into the open somewhat mysterious cognitive abilities of designers" [9]. It is difficult to imagine how else we might examine what people are thinking, except by asking them to tell us, although people do not necessarily verbalise what they are thinking when they perform a task [9]. In essence, protocol analysis relies on the verbal data produced by subjects of their own cognitive activities.

The rest of the paper is organised as follows. In section 2, the experiments used to investigate the links between a design and learning process are detailed. The observation results on the occurrence of learning and the relationships between the elements for learning and design are presented in section 3. Section 4 presents the findings of the research. Section 5 concludes the paper.

2 The experiments

Three experiments were carried out in which team design meetings were recorded using a video camera. In the first experiment, a meeting session of a student design team (called team one) was recorded. There were four team members, from the fifth (final) year of the Masters of Engineering Product Design Course from the Department of Design, Manufacturing, and Engineering Management, University of Strathclyde. The team members are represented as *DB*, *GM*, *MH*, and *PH* in the protocol. Within the meeting, the students were tasked with designing a concept for a fluid delivery system for a 3D (three dimensional) printer. The team designed the lip of the cartridge in the printer, means to seal the tube between the cartridge and the tank, the size and volume of the tank, the way to replace the tank, and the layout of the printer. During the meeting, the designers used pen and paper to sketch their design ideas. The sketches drawn were used to assist in understanding the verbal data captured during the protocol analysis. The whole design session lasted one hour and thirteen minutes. In the recording process, the recorder moved around the meeting area and recorded both the overall view and the local views. The overall views captured the overall interaction of the designers. The local view captured the gestures and sketch activities of individual designers.

In the second and third experiment, another design team was used, called team two, with two design meetings of the team recorded. In the first meeting, there were six members, composed of two fifth year students from the product design course (*CF* and *NB*), two fifth year students from the manufacturing course in the above department (*KS* and *MM*), a team design project advisor (*AF*) and a designer (*AT*) from the client company. They were tasked with redesigning a bitumen tank for road construction. Drawings of past designs were available for their reference. In the meeting, they designed the insulation, the heating elements, the bottom layout, and the connection between the inner and outer tank. The session lasted one hour and three minutes. The second session of the recorded meetings involved the same members, except the client (*AF*) and the course advisor (*AT*), working on the same project. In the meeting, they focused on designing the size, the heating pipe, and the cross-sections of the tank. It lasted one hour and twenty-one minutes. During these two meetings, they sometimes made references to the past drawings during their discussions.

The tapes were transcribed and encoded using the coding scheme described in [4], which is based upon the elements for design and learning activities identified *a priori*. The encoded data was analysed and used to indicate the links between the design and learning process.

The protocol analysis was supplemented with interviews of the participants. During the interviews, the recorded tapes were used to remind the participants of the design meetings. Questions, such as "did collective learning occur in this design activity?", "what did you learn in this particular design activity", and "what triggered you to learn?", were asked. The "supplemented protocol analysis" was carried out to check the encoded data and analysis results and to make the analysis more objective. As a result, it was found that some encoded data was biased, which was modified and re-encoded.

3 Observations

This section presents the observation results on occurrence of learning, and the relationships between the elements for design and learning.

3.1 Occurrence of learning

Some key words, phrases or sentences can be considered to explicitly indicate that collective learning occur, such as: (1) "Because Gerry said so" (*GM*)[1]; (2) "Aye, I get that bit" (*GM*), "Do you understand that Gillian?"(*PH*) "Yeah" (*GM*); (3) "Do you know what I mean?" (*MH*), "Yeah" (*GM*); and (4) "Right, see now I understand what the diagram (i.e. a diagram drawn by *DB*) is where I didn't actually really know" (*GM*). The protocol in (1) indicates that *GM* learned a piece of knowledge from Gerry. Example (2) implies that *GM* learned a design idea from *PH*. Example (3) indicates that *GM* learned a piece of knowledge from *MH*. From example (4), it can be inferred that *GM* learned from *DB*. In some examples, collective learning was identified by some key words, phrases or sentences that implicitly indicate its occurrence. The sentence, "Paul sketched one the other day and it is just like a rack and pinion type thing" (*GM*), indicates that *GM* learned a design idea from Paul. Collective learning can also be identified from the context of the verbal data. Table 1 shows that *GM* suggested that the cartridge did not have to be sealed, indicated from the verbalisation "that doesn't have to be sealed". However, with *PH*'s input knowledge that it would have the problem of contamination, identified by the key words "don't want it to be contaminated with dust as well", *GM* learned that the cartridge had to be sealed, indicated by her verbalization "aye, it would definitely have to be sealed…" *GM*'s knowledge state changed from the cartridge "doesn't have to be sealed" to "it would definitely have to be sealed".

Table 1 Collective learning inferred from the context of the verbal data[2]

[1] *GM* represents the designer who verbalises the words.
[2] The italic words represent the key words, phrases and sentences used to identify the elements of a team design activity and a collective learning activity.

No.	Transcript
18	GM: *That doesn't have to be sealed* (pointing to drawing) because as long as that water level's there you're not gonna get any water in it. They're not gonna get any air in it rather. As long as it's down to like there, know what I mean, as long as that bit's covered. DB: Even there, if it's running through a sponge then you're not gonna get any air through it anyway. PH: *Don't want it contaminated with dust as well*, you know you want to keep it quite... GM: *Aye, it would definitely have to be a sealed*...

Collective learning did not occur in all team design activities. Figure 1 describes the occurrence of collective learning throughout the meeting session of team one. The value "1" in *y*-axis represents the occurrence of collective learning within the duration of the design process, and "0" represents no collective learning. It seems that within 13 minutes from start, between 20 minutes and 45 minutes, and between 52 minutes and 70 minutes collective learning activity occurred more frequently than other periods in the design process. Twenty-nine learning activities in team one meeting session were observed.

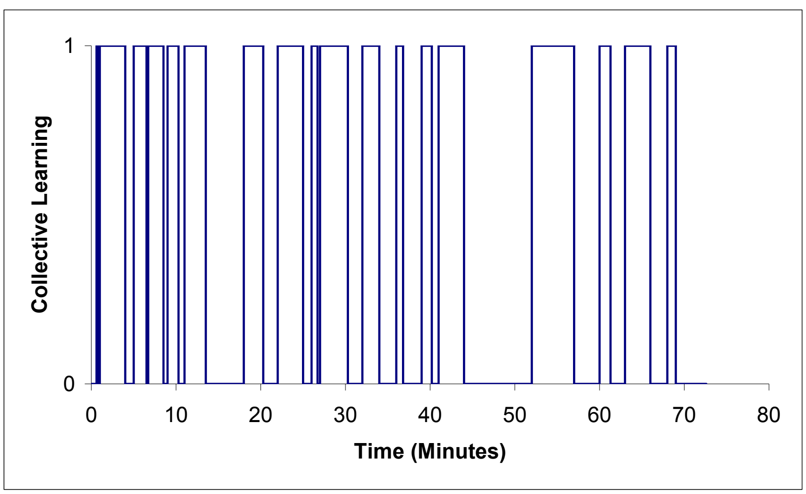

Figure 1 The occurrence of collective learning in team one

The occurrence of collective learning during the meeting sessions of team two is shown in Figure 2 and Figure 3. There were twenty-four collective learning activities in session one and twenty-five in session two identified. Collective learning in team design process was not always apparent in all design activities.

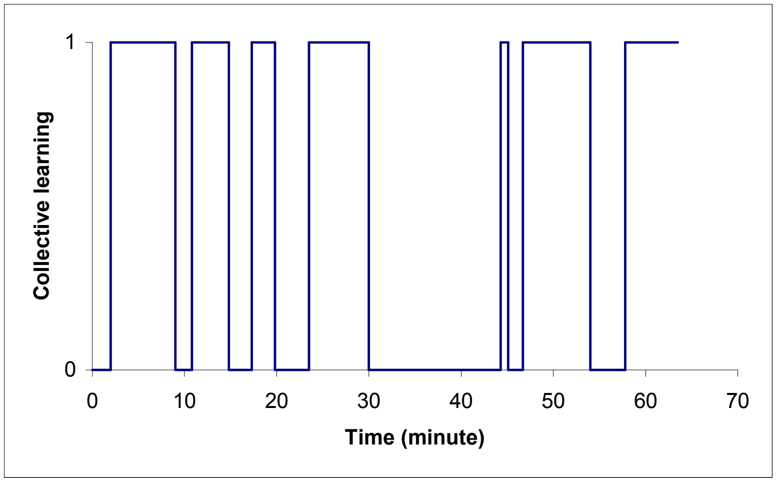

Figure 2 Collective learning in session one of team two

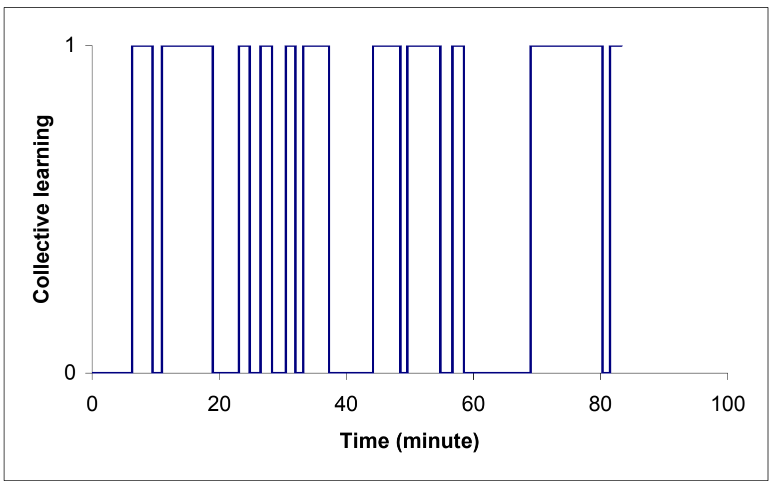

Figure 3 Collective learning in session two of team two

It should be noted that a learning activity could occur without direct link with a design activity. For example, Table 2 shows that *GM* learned *PH*'s design idea by his explanation, indicated from *GM*'s verbalisation "(pointing) what is that?" and *PH*'s key sentences "that's a hole" and "that is the hole for the tube so just tuck it in – snap fit, just push out". However, no design activity was identified within the protocol. *PH* explained his design idea that was drawn in diagrams to *GM*, which triggered her to learn. Since there was no knowledge increment to the design itself, it is not considered as a design activity.

Table 2 A learning activity identified

No.	Transcript
21	PH:(drawing) Set it on to two clips and just press it in. There you go there's the design. GM: (pointing) What's that? PH: That's a hole. PH: That's the hole for the tube so just tuck it in - snap fit, just push out. GM: *Aye, I get that bit.*

3.2 Input knowledge for design and learning

Input knowledge for design activities and learning activities usually follows the verbalisation of the team design goal and learning goal. The input knowledge could be from one participant or more and can be similar or conflicting [4].

The input knowledge for a collective learning activity can be related to those for a team design activity. The input knowledge for a collective learning activity can be the same as that for a design activity. For example, in the protocol in Table 3, the input knowledge for the team design activity is the same as that for *PH*'s learning activity. The goal of the design activity is to design a way to seal the tube, indicated from *GM*'s verbalisation "we need to design something to seal the tube so it doesn't leak". *DB* provided a way to seal the tube, using grub screws with a plastic sleeve around it, indicated from his verbalisation "grub screws?" and "with a plastic sleeve around it". *PH* had the goal to learn how a grub screw can be used to seal the tube, inferred from his question "where do we put a grub screw at the side to keep it tight?" *DB* provided the input knowledge of using a plastic sleeve around grub screws for *PH*'s learning activity, which was the same as *DB*'s input knowledge for the design activity.

Table 3 An example of input knowledge for a design activity being the same as that for a learning activity

No	Transcript
5	GM: *We need to design something to seal the tube so it doesn't leak, whether it is choosing a component like a rubber grommet, because we cannot just ram the tubes in.* DB: Grub screws? PH: *Where do we put a grub screw at the side to keep it tight?* DB: With a plastic sleeve around it, it would not have too much definition. (Drawing a design option)

The input knowledge for a collective learning activity can be part of that for a design activity. In the protocol in Table 4, four participants *GM*, *PH*, *MH*, and *DB* provided input knowledge for the design activity to seal the cartridge. *PH* had the input knowledge of using a small gasket, indicated from "just a small gasket that seals around". *GM* suggested using silicon gel round the top, implied from her key words "even just use silicon gel round the top". *DB* suggested that the three compartments should be sealed across, indicated from his verbalisation "because it's three you'd have to have rigid edges round here and a seal across…". *MH* suggested that the edge should be cut flat so that the cartridge could be sealed, indicated from his verbalisation "if you cut it well enough you should get it pretty close". However, the input knowledge for *GM*'s learning activity only came from *MH*. *GM* had the goal to learn whether they could use "silicon binder stuff" to seal the cartridge, indicated from her question "could you not have the silicon binder stuff just going along all these surfaces and just stick the top on?" *MH* suggested that if the surface was flat enough, it could be sealed by a silicon binder, indicating from his key sentences "if you cut it well enough you should get it pretty close" and "as long as it's flat" In this design activity, *GM* learned that if the surface of the cartridge was cut flat, they could use the "silicon gel stuff" to seal the cartridge. Thus, in this example, four designers *GM*, *PH*, *MH*, and *DB* provided input knowledge for a design activity, only one participant *MH* provided input knowledge for *GM*'s learning activity.

Table 4 Input knowledge of a learning activity being part of that of a design activity

No.	Transcript
12	GM: *I think it should be sealed along those edges so that the whole thing is sealed.* PH: What about a small gasket? GM: What do you mean? PH: *Just a small gasket that seals around, but I don't know how you'd get that done and how you'd seal it.* GM: *Even just use silicon gel round the top.* DB: But because it's 3 compartments...Easier if it's just a single compartment. But because it's the three *you'd have to have rigid edges round here and a seal across...* PH: Seal across here and here... you could possibly have it coming in ... GM: *Could you not have the silicon binder stuff just going along all these surfaces and just stick the top on?* MH: If you cut it well enough you should get it pretty close. MH: As long as it's flat.

3.3 Learned knowledge and output knowledge

The types of learned knowledge proposed by Grecu and Brown [10] were observed in the student design teams, namely *constraints relating parameters or other elements of the design*, *dependencies between design parameters*, *support in favour of or against a decision*, *design rules, methods, and plans*, *preferences*, *conditions for rules, actions, and tasks*, *consequences of design decisions*, *failures and conflicts*, *heuristics for failure recovery and conflict resolution,* and *successful design and design processes.* Two types of knowledge are identified that can only be learned collectively, namely common knowledge, and knowledge on the knowledge states of other participants, which are based on either of the two criteria: (1) the learning activities must involve two participants or more; (2) there should be interactions between participants in the learning process. Common knowledge is defined as the knowledge known by all the participants in a team. A participant can learn the knowledge of which participants have what kind of knowledge.

The identification of output knowledge could be inferred or derived from the input knowledge of participants and their design goals. The output knowledge in the design activity in Table 5 (i.e. the cartridge should not be sealed) was derived from the input knowledge from *GM* (i.e. the fluid will pour out and the cartridge should not be sealed) and the design goal (i.e. deciding whether the cartridge should be sealed or not), indicated from "no..., which was part of it but even then it shouldn't, because it was totally pouring out" and *MH*'s verbalisation "Was it sealed though?"

Learned knowledge can be part of or the same as the output knowledge of a team design activity. Table 4 illustrates an example in which learned knowledge was part of the output knowledge of the design activity. *GM* learned that silicon binder could be used to seal the edges of the cartridge if they were cut flat, indicated from *GM*'s verbalisation "Could you not have the silicon binder stuff just going along all these surfaces and just stick the top on?" and *MH*'s verbalisation "if you cut it well enough you should get it pretty close" and "as long as it's flat". While the output knowledge of the team design activity is *different* ways to seal the edges of the cartridge. Table 5 illustrates an example in which learned knowledge is the same as the output knowledge of a design activity. *MH* learned that the cartridge should not be sealed, inferred from *MH*'s verbalisation "Was it sealed though?" and *GM*'s verbalisation "No..., which was part of it but even then it shouldn't, because it was totally pouring out like" and *MH*'s second verbalisation "But even if it was sealed. It probably put too much pressure on the thing. Because it was totally flooding out at the rate at which it just comes out normally". The output knowledge of the design activity was the same as *MH*'s learned knowledge.

Table 5 Learned knowledge being the same as output knowledge

No.	Transcript
3	MH: *Was it sealed though?* GM: *No...*, which was part of it but even then it shouldn't, because it was totally pouring out like. MH: *But even* if it was sealed. *It probably put too much pressure on the thing.* Because it was totally flooding out at the rate at which it just comes out normally.

3.4 Learned knowledge and design input knowledge

Knowledge learned during the design process can be used as input knowledge in some design activities. For example, Table 6 shows that *GM* learned from *RC* (*Ryan*) and *PH* (*Paul*) who had the ideas to use a syringe to control the flow, indicating from *GM*'s verbalisation "can we not have one of those remote control syringe things that Ryan was talking about?" and "Paul (*PH*) sketched one the other day and it is just like a rack and pinion type thing". She used the learned knowledge as input knowledge for the design activity. Table 7 illustrates another example of learned knowledge used as input knowledge for design activities. Before the design meeting session, *GM* learned that they have to use a cartridge because they were using the cradle, indicated from the verbal protocol "Right, we have to use cartridge because we are using the cradle. Because Gerry said so". The learned knowledge was used as input knowledge in their following 3D printer design activities in the meeting session.

Table 6 Learned knowledge used as input knowledge for design

No.	Transcript
10	GM: We can do that, but *we still have to decide* how to meter off the flow at the top end. That's gonna be like a syringe or something... *Can we not have one of those remote control syringe things that Ryan was talking about*? You control medical doses by having a gradual plunger thing, (draws) designed to steadily go down. *Paul sketched one the other day and it is just like a rack and pinion type thing*. (Explains diagram ...)

Table 7 Another example of learned knowledge used as input knowledge for a design activity

No	Transcript
1	GM: Right, we have to use a cartridge because we are using the cradle. *Because Gerry said so*. So we have to design a little bit to go on the top of this about this topic. DB: *Yeah*. It is not just the tube into the ink recess or whatever it is called. MH: *Yeah*

3.5 Design output knowledge and input knowledge for learning

The output knowledge from design activities can be used as input knowledge for a learning activity. For example, Table 8 depicts that the design idea produced by *DB* and *GM* triggers *MH* to learn, indicating from *DB*, *GM*, and *MH*'s verbalisation "…I'm trying to think of an example. You know the kind of the thing I'm talking about", "Yeah, like the steradent tops?", "Aye, that idea", and "Aye, that's a good idea"

Table 8 Design output knowledge triggers a learning activity

No.	Transcript
26	DB: That just fits in the top - *I'm trying to think of an example. You know the kind of thing I'm talking about.* GM: *Yeah, like the Steradent tops?* DB: *Aye,* is that the stuff they use for dentures? GM: *Yeah.* DB: *Aye, that idea.* MH: (drawing) *Aye, like this - is it like that, is that what you're talking about?* And you push them back down. DB/GM: Yeah MH: *Aye, that's a good idea.*

3.6 Learning goal and design goal

It is difficult to identify learning goals, as the individuals did not verbalise such words as "the goal I learn from him/her is …" However, learning goals can be identified through key words or phrases or sentences, and it could also be inferred from design goals, input knowledge, and learned knowledge. In the learning activity in Table 5, the learning goal of *MH* on deciding whether the cartridge was sealed or not was identified based upon the sentence "Was it sealed though?"

There are some learning activities without a learning goal. In those learning activities, participants learned from others only because other participants verbalised some knowledge. For example, within the protocol in Table 9, it was identified that *GM* learned from *PH* the design idea of using a clip to attach the gadget to the cartridge, indicated from *PH*'s key words "if you clip your print cartridge in and this is attached (holding gadget)" and *GM*'s key word "yeah" There was no apparent learning goal in this learning activity. *GM* learned from *PH* because *PH* verbalised his design idea during their discussions.

Table 9 Collective learning without learning goal identified

No.	Transcript
15	PH: So what if you have it in two bits - what if you have a clip? If you clip your print cartridge in and this is attached (holding gadget). You know you have your bottle or whatever. It doesn't matter where your bottle is if its gravity feed you know you just need to sit it above. GM: *Yeah*

Team design goals in 82% of the identified design activities were verbalised at the beginning of the protocol segments. The key words used to identify team design goals were like "We need to design a lid...” (*GM*), “We need to design something to seal the tube…” (*GM*) and “I still think we need something to stop the flow….” (*MH*), in which the design goals were inferred as designing a lid, designing something to seal the tube, and designing something to stop the flow. Design goals were also inferred from the questions verbalised by the participants. For example, from the questions “Right, what about the mounting of the tank then? Do you think it should be on the gantry or moving with it?” (*GM*), the team design goal was identified as deciding the location to mount the tank.

It was identified that the learning and design goals interacted with each other in two ways: the learning goal preceded the design goal, or vice versa. Table 10 illustrates an example in which *GM*’s goal to learn the way to control the flow preceded the goal to design a way to control the flow. Table 11 depicts that the team’s design goal to seal the entry point of the tube preceded *PH*’s goal to learn the way to keep the tube tight.

Table 10 An example of learning goal preceding design goal

No.	Transcript
7	GM: *Is there any way that we can incorporate the valve that operates and that is also run by the processor in the computer?* So that when that is reaching out it allows the flow to reach in. GM*: Is there any other way to do it when it is being controlled?* MH: *Just put a valve on it* or something. PH: You can control the reservoir as it is we talk about having *an injection system* rather have a valve on it, having a controller and the plunger to have a certain amount coming out at one time. GM: You *are not control* the level at the cartridge. PH: *That will* control the amount that was getting leak out, if it is pressurised. GM: *Like at the top in the tank*? PH: *Yeah*.

Table 11 An example of design goal proceeding learning goal

No	Transcript
5	GM: *We need to design something to seal the tube* so it doesn’t leak, whether it is choosing a component like a rubber grommet, because we cannot just ram the tubes in. DB: Grub screws? PH: *Where do we put a grub screw at the side to keep it tight?* DB: With a plastic sleeve around it, it would not have too much definition. (Drawing a design option)

4 Findings

Based upon the observation results in section 3, the nature of the links between a design and learning activities are concluded as follows:

- The input knowledge for a collective learning activity can be part of or the same as that for a design activity. Examples were shown in Table 3 and Table 4.
- Learned knowledge can be part of or the same as the output knowledge of a team design activity (see examples illustrated in Table 4 and Table 5).
- Knowledge learned during a design process can be used as input knowledge in some design activities, illustrated through the example in Table 6 and Table 7.
- Output knowledge from design activities can be used as input knowledge for a learning activity, depicted by the example in Table 8.
- Learning and design goals interacted with each other in two ways: learning goals preceded design goals, or vice versa, explained through the examples in Table 10 and Table 11.

The findings are consistent with those reported in [2] in that a design and learning activity can be separated or intertwined. They provide insights on how these two types of activities are linked with each other by revealing the relationships between the elements of the activities.

5 Conclusion

This paper presented identified links between the design and learning processes in the context of team design. The links were identified by a "supplemented protocol analysis" of team design activities. Three experiments were carried out to investigate the links, with three meeting sessions in two design teams recorded. The finding results are consistent with those reported in [2]. However, they revealed more insights on how the two types of activities are linked by identifying the relationships between the elements of the activities. That is, input knowledge or learned knowledge for a learning activity can be part or the same as that of input knowledge or output knowledge for a design activity. Output knowledge from a design activity can be used as input knowledge for a learning activity. Learning goals can precede design goals, or vice versa.

In the future, the research can be extended to investigate professional design teams rather than students. Students are still in their active learning stage and generally have limited work experience. The way students work is different from that of professional designers. As such, the links between the learning and design processes can be different. Also, although three experiments were carried out with more than one-hour duration for each, the observations of the design and learning are still not enough. More observations need to evaluate the results proposed in this paper.

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