

## 4 Lynn's protocol

Lynn divides her professional life between her own design studio and working for other product design, interior design and branding consultancies. When this protocol was recorded in November 2006 she had approximately nine years professional experience as an architect and product designer. Her qualifications include a BA in architecture and an MA in product design (gained at the Royal College of Art).

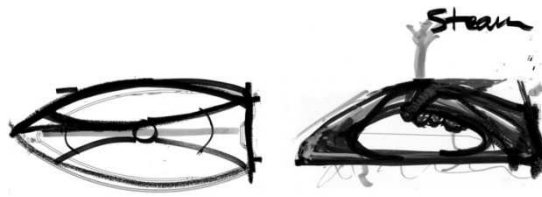


Figure 4-1 the design representations generated during this protocol

Because of the portmanteau nature of her professional life Lynn often works in a variety of different, and sometimes unconventional, spaces. To Lynn any space which allows her to lay out her laptop and sketchbook *is* her 'studio', albeit a temporary one. This informal approach to workspaces is reflected in her protocol which was recorded in the living-room of her home.

This chapter is divided into six sections. The first establishes the position of Lynn's protocol in relation to those described in the subsequent chapters, while the second gives an overview of the kind, and number of design actions contained in it. The third section describes those actions which took place after the protocol had commenced, but before any shape generation actions had been observed, while the fourth lays out a full description of Lynn's drawing actions as a series of individual episodes. The fifth section completes the description of Lynn's protocol by giving an account of her actions after its end, i.e., after any observable shape generation activity has ceased.

The final section contains an initial analysis of the data laid out in this chapter. This centres on the categorisation of design actions (4.6.1), on mapping categories of design actions against algebras of shapes (4.6.2), the decomposition and embedding of shapes observed in the protocol (4.6.3), on quantifying and comparing design actions (4.6.4), on representational constraints (4.6.5) and to what extent the participant's design actions could

be seen as designing three-dimensional forms as opposed to drawing two-dimensional shapes (4.6.6). The initial findings from these areas are discussed in the final sub-section, endnotes (4.6.7).

#### 4.1 Lynn's protocol in context

Lynn's protocol serves as a useful introduction to the subsequent protocol chapters as it is the shortest and least complicated, containing only two separate instances of design representations and fifty-nine discrete design actions.

Furthermore, in Lynn's protocol it is always possible to see the effect of her actions on her design representations clearly. The relationship between the still images, taken directly from the video record at the beginning and end of each design action, and the CAD-based recreation of that action is also clear. In subsequent protocols, in part because of the limitations on camera positions imposed by the non-invasive data collection methods employed here, and in part by the less bold mark-making practices of the other participants, these transformations are not always so clearly visible. In these cases the CAD-based recreations of design actions have had to be 'reverse-engineered' instead. Where this has proved necessary it has been achieved by matching the participants' drawing or shaping actions with either the shapes or surfaces that remain in the final version of the representation, or those shapes or surfaces that can be discerned in subsequent frames in the video record more clearly.

It is also possible throughout this particular protocol, and in the initial drawing sections of the remaining protocols, to unambiguously identify individual episodes of representation making activity. Episodes are defined in such a way that, at least in the initial drawing stages of each protocol, they are synonymous with the use of a single instance of a design representation. In these episodes the transformational space occupied by a design element (those parts of the design representation that the designer acts on in any single design action) is also consistent with the upper spatial degree of the representation itself. In later protocols, those which entail making a three-dimensional representation, while it is obvious that the particular instance of a design representation *is* a three-dimensional one, what is not so apparent in each design action is the space which the design elements themselves are

transformed in. The divisions between 'making' episodes in subsequent protocols are necessarily much less clear-cut than those contained in Lynn's 'drawing' episodes. Lynn's protocol, therefore, is used here to demonstrate the principle of episode division (as it is employed throughout this and the remaining protocols) on an unambiguous example.

#### **4.2 Summary of design actions observed in the protocol**

Lynn stopped approximately forty minutes into her protocol after producing two sketches, one each of a plan and elevation of her design proposal. In producing these sketches Lynn chose to draw directly over relevant copies of the supplied full-size plan view and side elevation drawings.

Fifty-nine discrete design actions were observed in total. All of these were generated in the twenty-five minutes and fifty-one seconds that lay between 08:48 and 34:39 into the protocol. They consisted of three distinct types of marks: forty-six were comprised of single linear strokes, in actions *L1-L14*, *L25-L53*, *L55* and *L56*, *L58* and *L59*, twelve were shaded areas comprised of a number of contiguous strokes, in actions *L15-L24*, *L54*, *L57*, while the remaining one, in action *L38*, was comprised of a combination of both a linear stroke and a shaded area.

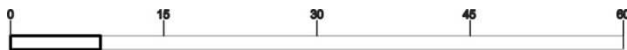
As well as creating new lines, three distinct ways of overdrawing existing lines were observed. The first involved tracing over the entire length of a previously drawn line; to make it bolder (in actions *L1*, *L25*, *L30 – L32*, *L42* and *L43*, *L49*, *L50* and *L51*, *L55*), while the second involved tracing over a segment of a previously drawn line; to select that segment of the line and separate it from the rest (in actions *L28*, *L30 – again*, *L34*, *L40*, *L52* and *L53*, *L58*). The line drawn in action *L30* combines both these actions as it is a combination of an over-drawing of a previously applied line (that drawn in action *L4*), and a decomposition of an apparently contiguous line which was compounded from the lines drawn in actions *L4* and *L5* (where the line drawn in action *L5* has sprung tangentially from the endpoint of that drawn in action *L4*).

The third form of over-drawing entailed tracing over two or more previously and separately applied lines, usually ones which were contiguous with (and tangential to) one another, thus joining them into one piece (as seen in actions *L27* and *L48*). Two significant

variations on this theme can be seen in the lines, and other marks, made in actions L29, L38, L41, L54 and L57. In actions L29 and L41 Lynn starts overdrawing an existing line but then continues it into a new line in one stroke, while in L38, L54 and L57, rather than using linear marks, she uses shaded areas instead to connect previously unconnected lines.

In addition to these fifty-nine discrete design actions there were also three examples of annotative mark-making observed in this protocol. All were made on the full-size side elevation. They were comprised of writing the word 'steam' at the top of the drawing (in section 4.4.1), adding a stylised plume of steam from the top of the iron (in section 4.4.3), and drawing a life-size representation of a hand gripping the handle area of the iron (in section 4.4.13).

### 4.3 Initial activities (00:00 – 08:48)



The protocol commences with Lynn working out how to correct the scale of the digital versions of the supplied drawings (which she had previously imported into Cobalt, a Mac-based digital modelling program), by using the calculator function of her mobile phone. As can be seen in the timeline at the head of this section, nearly nine minutes of preparatory activities elapse between the start of the protocol and Lynn making her first mark. A cursory breakdown of her activities in this period show that adjusting the scale of the drawings in Cobalt took approximately five minutes (from 00:23 to 05:39), while a further minute approximately (from 05:39 to 06:30) was spent looking through the supplied printed copies of those drawings.

At 06:30 she opens her sketch pad for the first time. Initially this was oriented in portrait format but, after a moment's reflection, she rotates it to a landscape format instead. It was still in this orientation when she began making marks at 08:48. Rather than beginning to draw at this point she instead places the supplied model of the iron base on top of the sketch pad, on her right-hand side, and the set of half scale drawings on top of a fresh sheet in the sketch pad on the left.

At 06:55 she picks up the base model, begins to examine it, and makes a comment on the importance of physical objects for determining scale: 'What I like about having

something as reference is that everything is a certain size for a reason'. At 07:37 she makes a further comment, inspired by an unintentional feature of the iron base model (to save on rapid-prototyping costs it had been made as a thin-walled object with an open base, rather than as a solid object): 'I really like the idea that this is a shell'.

At 08:17 she finally picks up her pen, apparently in preparation for making a mark, but immediately puts it down once more and begins to trace out shapes with her hands instead, apparently morphokinetically rehearsing the kinds of forms that might be suitable for the upper section of the domestic clothes iron, in and around the area immediately above the *inverted* iron base model. After this she flips the iron base model from an inverted back to an upright orientation, and then immediately back to an inverted orientation once again, explaining that it was this orientation that had inspired her thoughts about a shell based design.

At 08:48 she selects one of the supplied full-size side elevations of the iron base and, finally, begins to draw on it.

#### 4.4 Drawing episodes (08:48 – 35:17)

##### 4.4.1 Full-size side elevation: first episode (08:48 – 09:51)

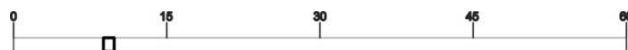
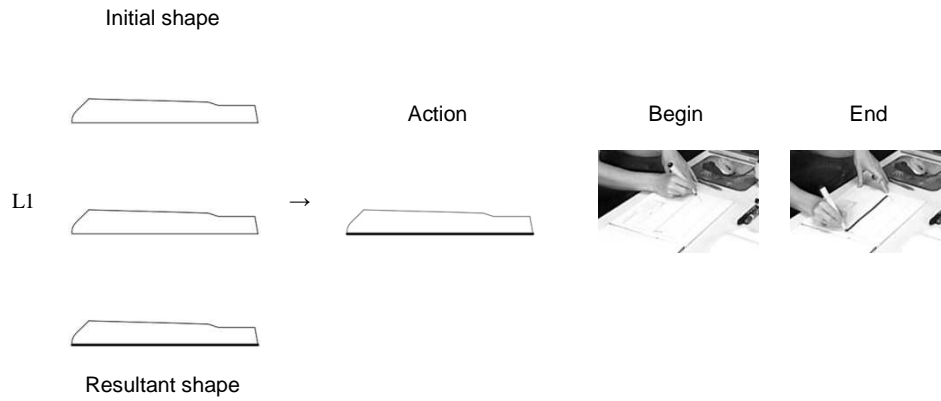
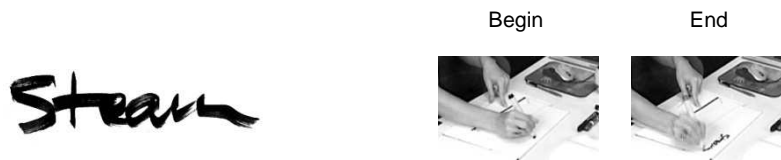


Figure 4-2 the completed full-size side elevation

Lynn's first action is to reinforce the base-line of the foot of the iron, in one of the supplied side elevation drawings, while verbally indicating to the author that the flatness of its foot is an important part of the function of any clothes iron.



While still considering the functional aspects of the design Lynn then annotates the side elevation drawing, writing the word 'steam' in the top right-hand corner, as a textual reminder of this.



The first episode, then, simply consists of reinforcing the line of the foot, in one of the supplied side elevation drawings, and making an annotative mark about a functional aspect of the design. Lynn now turns to one of the supplied plan views of the iron base.

#### 4.4.2 Full-size plan view: first episode (09:51 – 11:43)

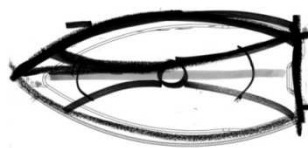
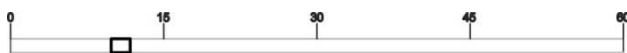
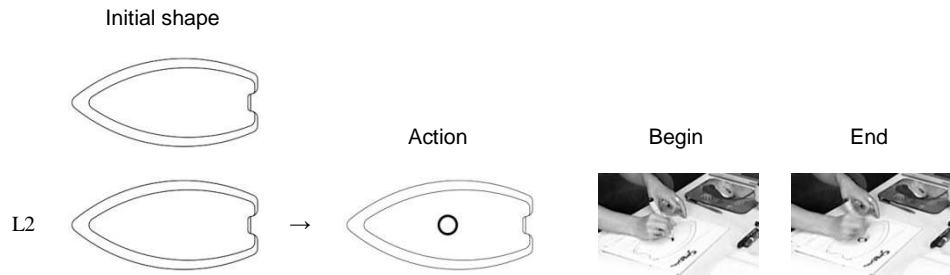
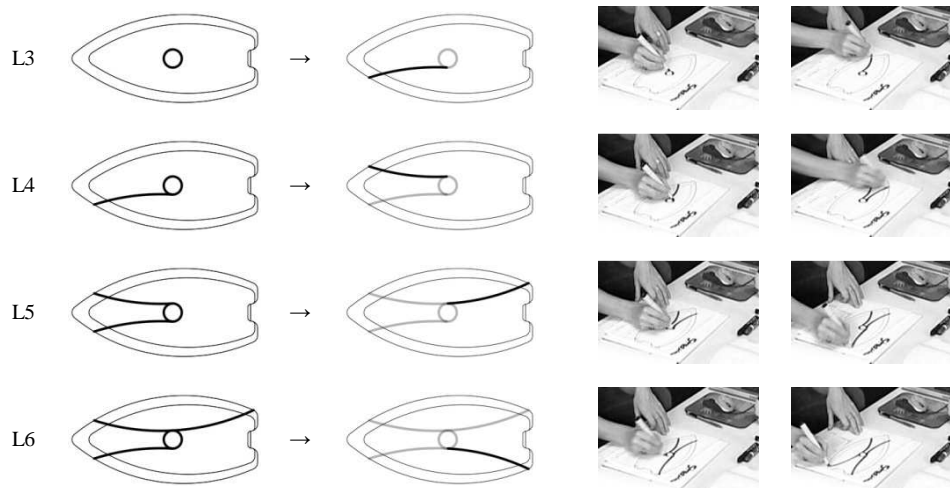


Figure 4-3 the completed full-size plan view

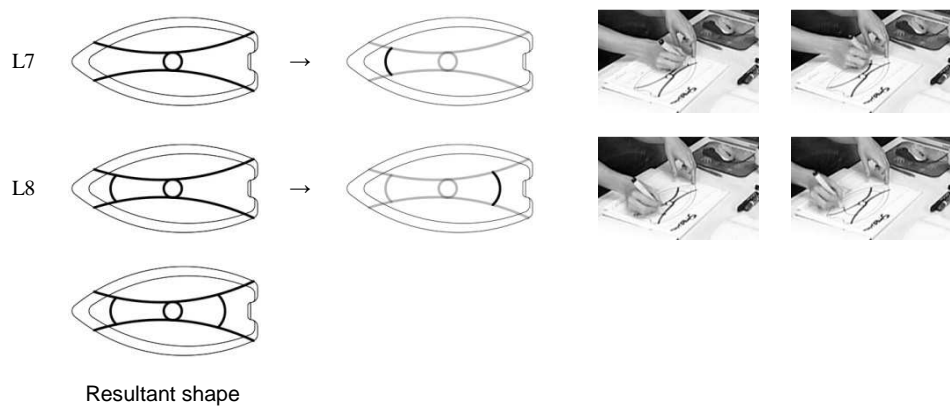
Continuing with the theme of considering steam as an important part of the function of an iron, Lynn begins to draw on the plan view of the iron base to establish the shape, size and position of the water filler (in action L2). This of course is the first entirely new shape in this protocol, i.e. one that has not previously appeared in the supplied materials.



The water filler drawn in action L2 is then connected by four curved marks (in actions L3, L4, L5 and L6), radiating out from it to the perimeter of the base's plan view, to establish handle contours. The initial lines drawn in actions L3 and L4 spring tangentially from the circle representing the water filler, while the subsequent lines, drawn in actions L5 and L6, are tangential extensions added to the lines drawn in actions L3 and L4.

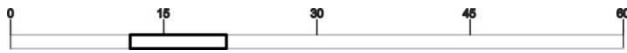


Two further curved lines (drawn in actions L7 and L8) are then added, connecting the lines drawn in actions L3 and L4, and L5 and L6, to establish notional split lines between the upper and lower sections of the body.

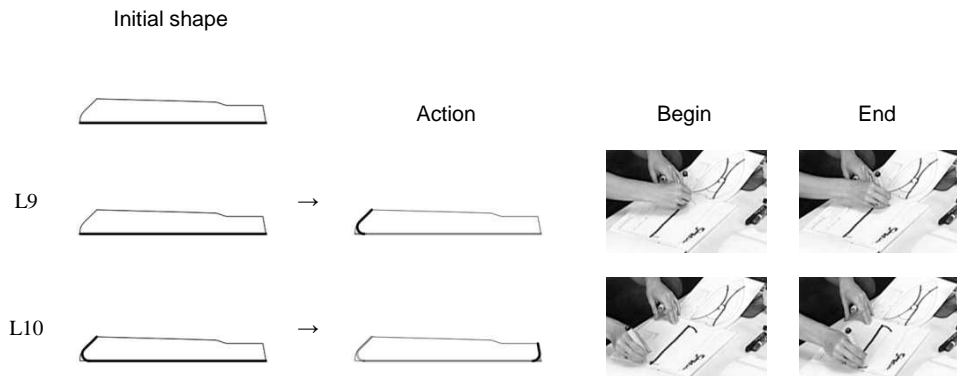


This first episode on the plan view establishes (in plan at least) the position, size and shape of the water filler, the outline profile of the handle, and potential split lines between the upper and lower sections of the proposed body design.

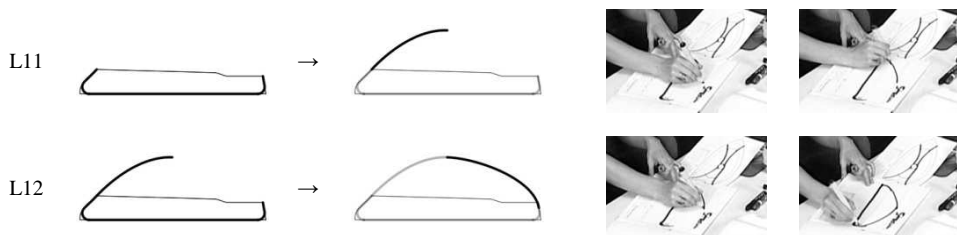
#### 4.4.3 Full-size side elevation: second episode (11:43 – 21:08)



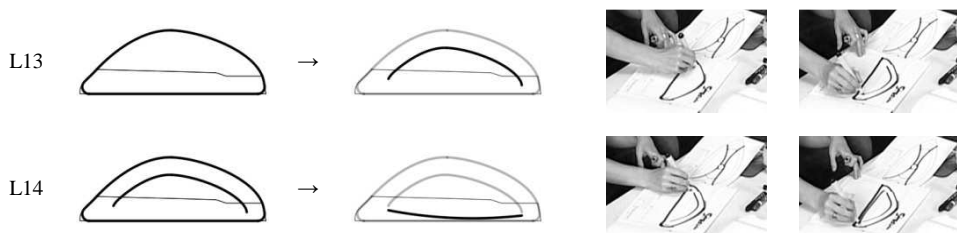
Returning to the side elevation, Lynn adds radii (in actions L9 and L10) to the bottom corners of the iron base. This would of course entail modifying the supplied base design's profile, and was an issue which remained unresolved at the end of the protocol.



Lynn then establishes the upper profile of the body with two curved elements (in actions L11 and L12). Both lines are drawn clockwise, from left to right, so that the line drawn in action L11 springs tangentially from the radius drawn in action L9, and the line drawn in action L12 springs tangentially from the line drawn in action L11. At its further end, the line drawn in action L12 also flows tangentially into the radius previously drawn in action L10. It should be noted that the rake angle, specified in the design brief, has not yet been allowed for.



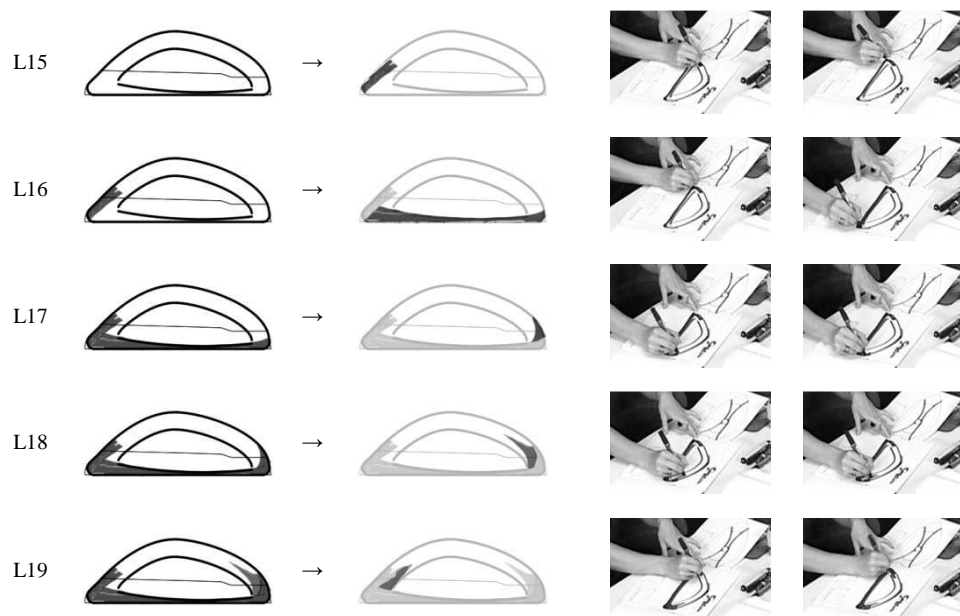
The upper and lower contours of the handle opening are now, unlike the previously drawn profile outlines, established with single strokes (in actions L13 and L14). These are again drawn from left to right, but stop a little short of connecting with one another.



Lynn now switches to a broader pen, and begins to define the metal areas of base. The single linear strokes she has employed so far now give way to shading actions on the side elevation, i.e., blocking out areas using a number of strokes instead of using single strokes to create lines.

Until now all of her design actions, with the exception of the annotative mark where she wrote the word 'steam', have consisted of making linear marks with a well defined beginning and end. In the following design actions they consist instead of a number of rapidly executed, overlapping strokes. In each of these compound design actions the mark making strokes are contiguous spatially and temporally with one another, and laid down without a significant pause between them. An individual design action in these cases is defined as any modification made to the design representation between the preceding pause in the designer's physical activity, for assessment of the previous action, and the subsequent pause for assessment of the effect of that modification of the design representation.

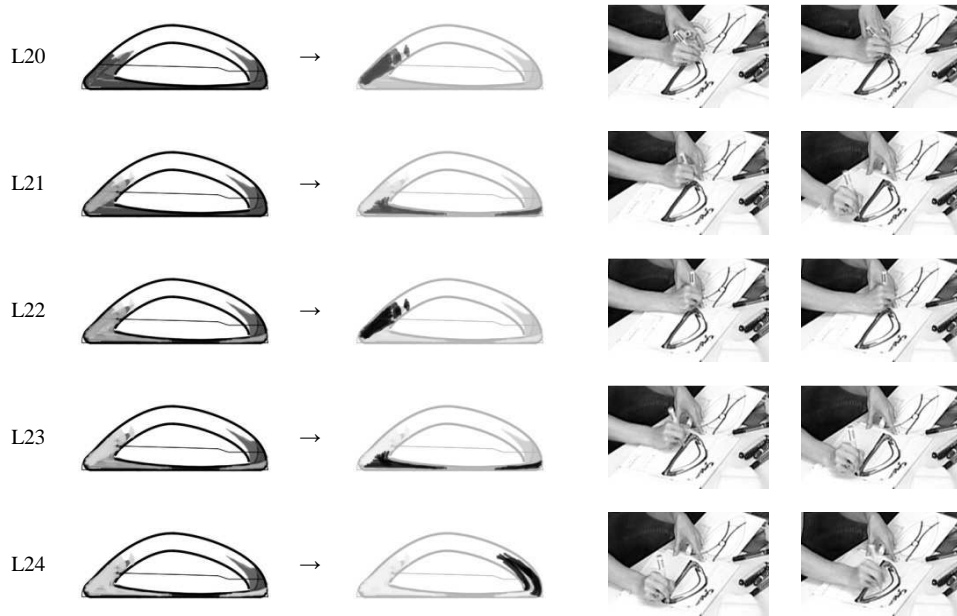
The individual design actions (L15 to L19) illustrated below, therefore consist of considerably more than five physical actions in total, but can be differentiated from one another by the pause for assessment that occurs between each one of them.



Lynn continues to define the metal area of the base with another series of compound actions, but here she modifies the previously applied compound actions with a lighter toned, solid colour pen. Here Lynn is effectively removing parts of the metal area of the base by overdrawing them with this solid tone. For the purposes of clarity these actions

have been shown in negative here; i.e., the darker the shape is in the rule, the greater the lightening effect of its application to the existing shape should be.

Actions L20 to L24 then, illustrated below, represent both an attempt by Lynn to modify the shapes she laid out in actions L15 to L19 and a further attempt to suggest a blending between the upper and lower areas of the iron body.



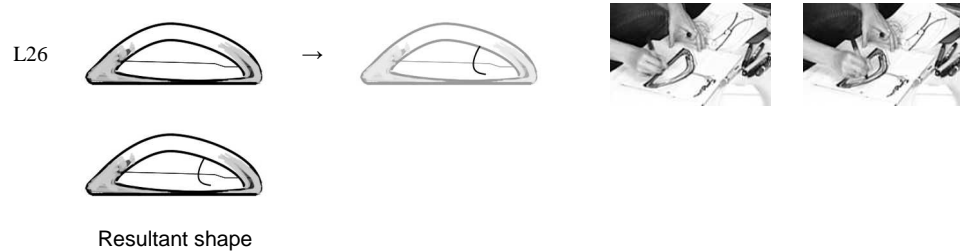
Lynn now returns to simple, linear mark making, as well as returning to the base line (drawn in action L1) to reinforce the shortened version of it created by the radii added in L9 and L10.



Having written the word steam in section 4.4.1 as a textual reminder of a functional aspect of the design, Lynn now draws its action as well. Here she makes a number of annotative marks to indicate how steam is intended to flow within the body of a domestic clothes iron, and how that flow is incorporated into the form of her design proposal (not included here for clarity). Lynn finishes this annotative mark-making by drawing collection of strokes representing a stylized plume of steam erupting from the water filler.

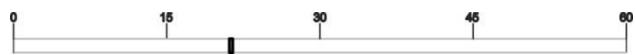


Almost as an afterthought, and before leaving the side elevation briefly to add a single mark to the plan view, Lynn also adds a short curved line (in action L26) to establish the rear of the handle opening.

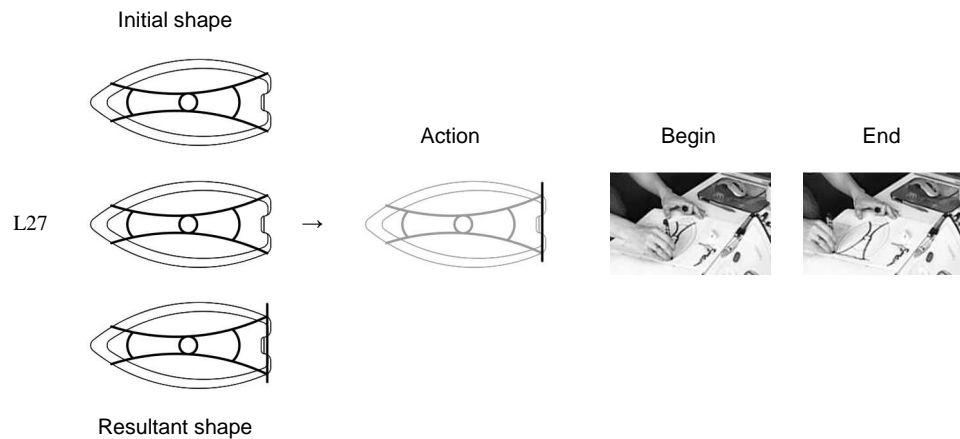


The design actions in this second episode on the side elevation establish the inner and outer perimeters of the iron's body, begin to suggest separate upper and lower areas within that body, and to divide the rear portion of the body from the front and handle areas.

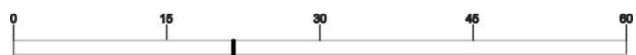
**4.4.4 Full-size plan view: second episode (21:08 – 21:27)**



Lynn turns away from the side elevation to work on the plan view, drawing a single line (in action L27) to establish the heel of the iron base. This reinforces and connects the existing lines on the supplied plan view, and extends them beyond the existing perimeter.

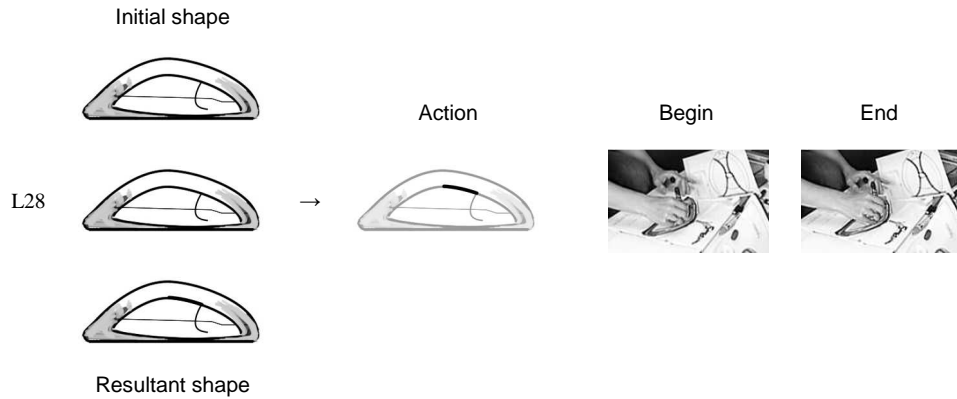


**4.4.5 Full-size side elevation: third episode (21:27 – 21:36)**



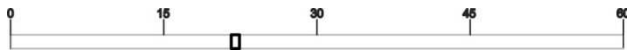
Like the previous episode, this one also contains only a single design action. This consists of a short line segment (in action L28), drawn directly over that depicting the

underside of the handle area (drawn in action L13), and immediately ahead of the previous line (from action L28) drawn in this view at the end of second episode on the side elevation. Rather than modifying the existing line this new one seems to be intended only to reinforce it in the grip area of the handle underside.

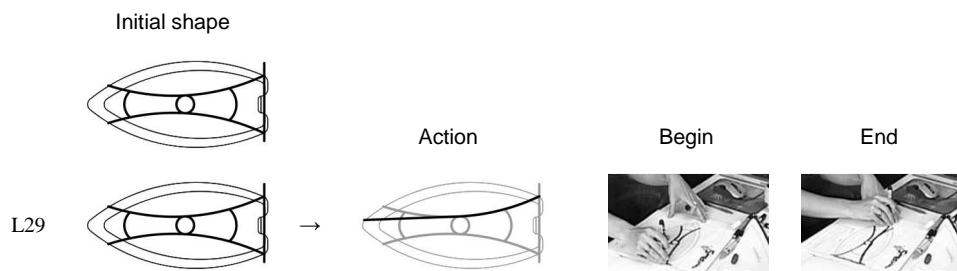


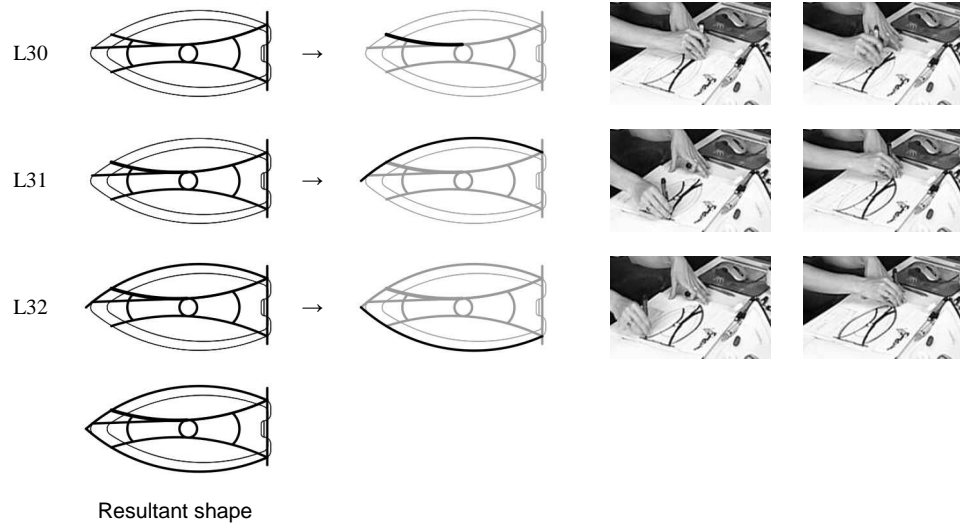
This is the first example of Lynn picking out a smaller element from an existing larger line and overdrawing it. At this point she immediately moves back to the plan view to work on the forward section of the iron, but actions L26, L27 and L28, although split up into episodes here, show Lynn's attention beginning to focus on the rear of the iron body as a separate area.

#### 4.4.6 Full-size plan view: third episode (21:36 – 22:24)



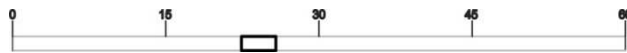
In her third episode on the plan view Lynn explores a variation on the handle contours, at the forward end in action L29, before apparently abandoning this option and reinforcing the original handle contour (in action L30). At this point she also reinforces the outer contours of the lower base (in actions L31 and L32), but modifies them slightly by connecting them together (in a point) ahead of the forward end of the base, rather than following the radiused line in the underlying drawing.





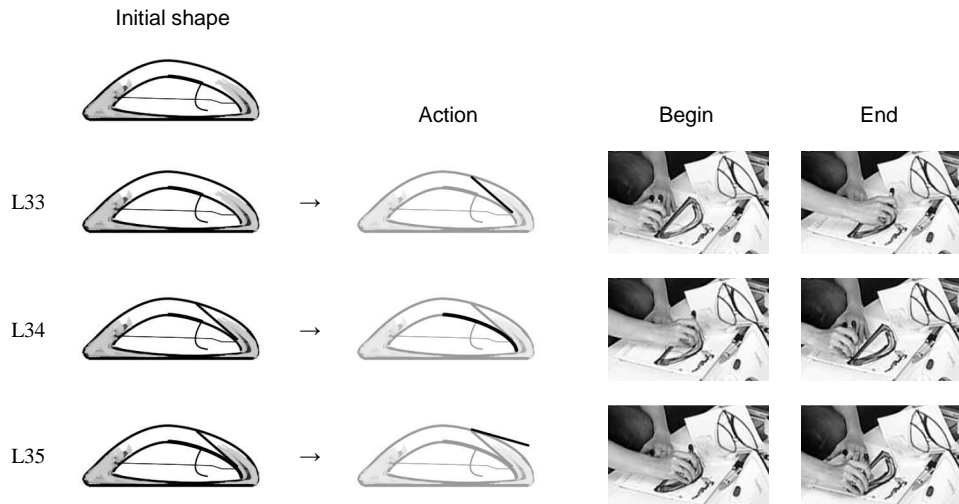
Although Lynn essays a possible variation in the front of the handle profile, and brings the front of the base to a point, she immediately de-emphasises the change made in action L29 in the subsequent action, and the plan view of her design proposal remains largely unaltered at the end of this episode.

#### 4.4.7 Full-size side elevation: fourth episode (22:24 – 25:47)



After re-reading the brief, and noting that it stipulates that a ten degree rake angle should be incorporated into the heel of the iron, to allow it to be rested in an upright position on the heel rather than on the heated element in the foot, Lynn now investigates three alternative profiles for the heel (in actions L36 to L38).

However, instead of moving directly to drawing an angled surface on the heel, she first draws three additional lines over the rear section of the body. The line drawn in action L33 appears to indicate a possible split line between the front and the rear halves, making this part a separate element in its own right. The line drawn in action L34 reinforces the element of the line that was reinforced in action L28, but now extends it further to the rear of the iron, incorporating an additional piece of the larger line that the element in action L28 was extracted from. Action L35 establishes a new, straightened upper line for the body which springs tangentially from the intersection of the line drawn in action L12 with the line drawn in action L33. This new upper line also creates the greater depth required in the rear part of the body if the heel section is to be incorporated into it.



Although the line drawn below, in action L36, is sloped at approximately ten degrees it is however, compared to normal practice in domestic clothes iron design, orientated in the opposite sense to that normally expected. It is also unlikely that this configuration would be particularly stable.



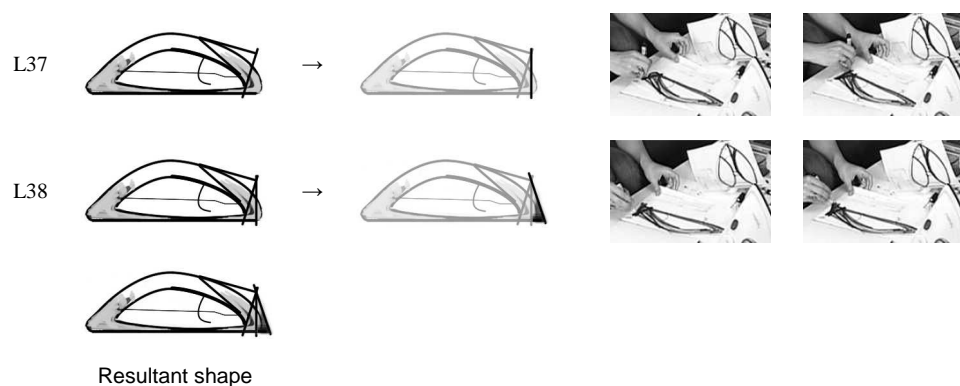
After drawing this first option Lynn rotates the side elevation drawing from landscape format to portrait format presumably, not only to make it easier to draw the subsequent lines representing the two further variations of heel angle, but also to make it easier to visualise the forces acting on the iron in its upright configuration, i.e., to make it easier to visualise the relationship between the iron's centre of gravity and the footprint of its heel. During her next episode of drawing on the side elevation she will switch between these two orientations again.

It is worth noting this change in orientation, as, although the physical representation itself is unchanged by it, the designer's perception of the shapes contained in that representation will inevitably be altered by it. However, for the purposes of coherence in these descriptions of design actions, this change in orientation will not be reflected in the illustrations of the design actions presented here, and throughout the remainder of this thesis.

Actions L37 and L38 show two further variations on the heel rake angle, which follow that drawn in action L36 in quick succession. The line drawn in action L37 also starts from the intersection of the lines drawn in actions L35 and L36 but, as it is drawn perpendicular

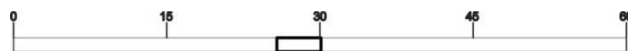
to the line representing the foot, has no rake angle. It can be seen, however, as approaching the desired orientation (which is achieved by the subsequent line drawn in action L38) in a step-wise fashion.

The mark made in action L38 also starts from the intersection of the lines drawn in actions L35 and L36, but rather than being a simple linear mark like the previous two, it is made up of both a linear mark *and* a compound shading action. Here, having drawn a straight line from the intersection of the lines drawn in actions L35 and L36 in an identical fashion to the previous two, but without lifting her pen, Lynn then continues to shade in an area at the base of this line to connect it with the existing one that represents the foot.

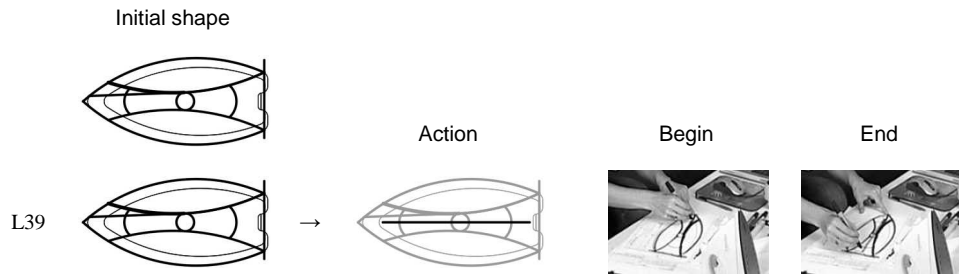


As well as further defining the rear end of the iron as a separate area, in this episode Lynn also transforms the outer perimeter of the iron body's side elevation, to take into account a functional requirement of the brief that had previously been overlooked.

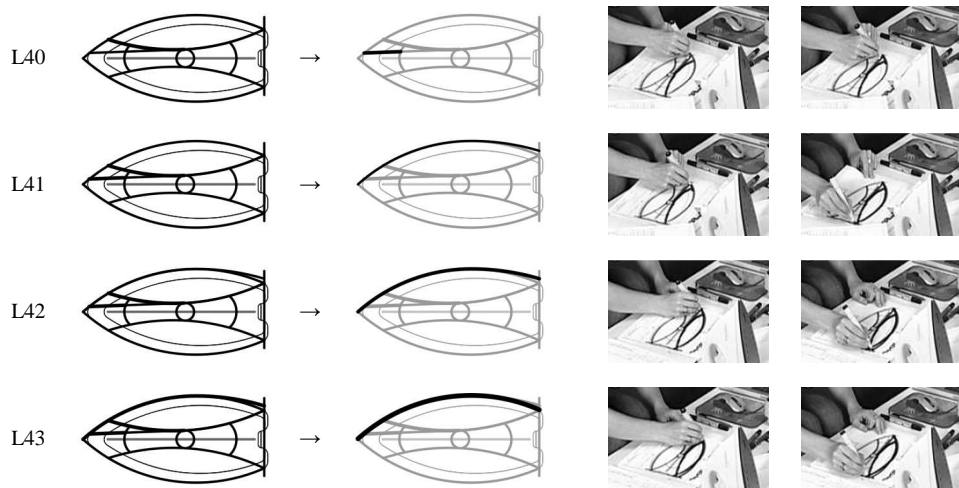
#### 4.4.8 Full-size plan view: final episode (25:47 – 30:05)



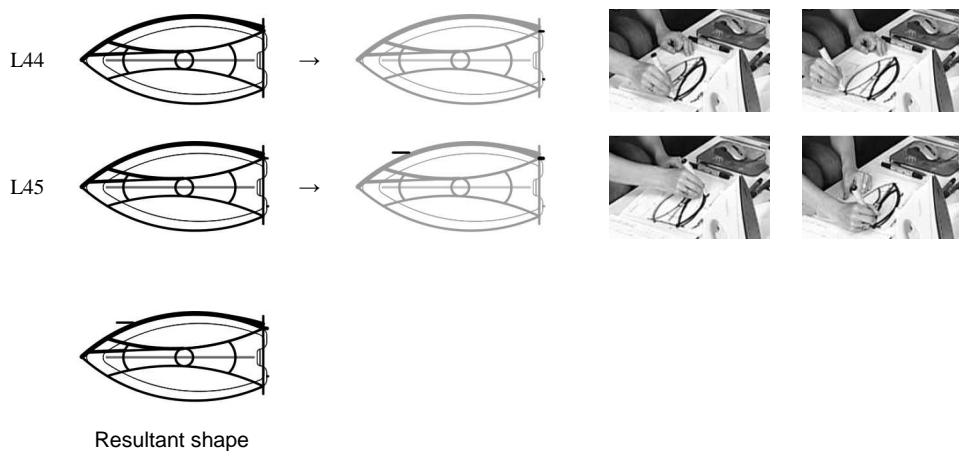
In the previous sections all the marks made by Lynn might conceivably have become one of the contours of a finished object. At this point, however, while still working on lines that *describe* shapes, she also begins to draw lines that, rather than being intended as part of the finished object, can be used to *construct* those contours instead. The first of these is illustrated below, when she establishes a centre line in the plan view in action L39:



Part of the alternative contour for the forward split line, essayed in action L29 and immediately countermanded in action L30, is now reinforced by the line drawn in action in L40. An alternative outer perimeter for the foot profile, drawn in action L42, which widens at the rear to meet the extended heel line introduced in action L27, is similarly undone by immediately reinforcing the original profile in action L43.



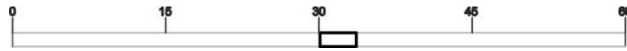
Further construction lines are added by establishing reference marks on the heel in action L44, and an approximately co-linear mark in action L45.



This final episode on the plan view makes the symmetry of the plan view explicit (in action L39) reviews, and reassesses, a previous option (in action L40), and reinforces an earlier option on one side of the plan only (in actions L42 and L43). Finally, Lynn also

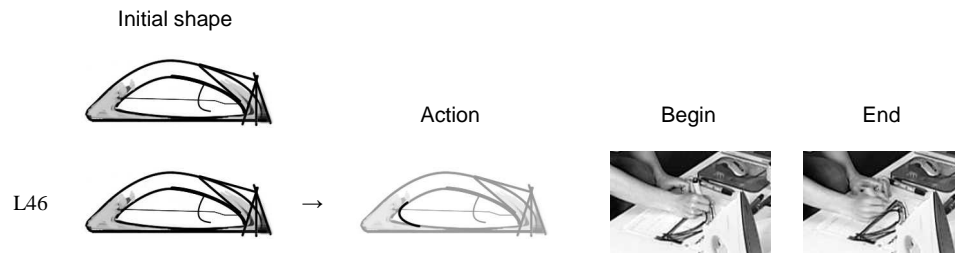
makes explicit relations between elements of the plan view with the constructional marks drawn in actions L44 and L45.

#### 4.4.9 Full-size side elevation: fifth episode (30:05 – 33:38)

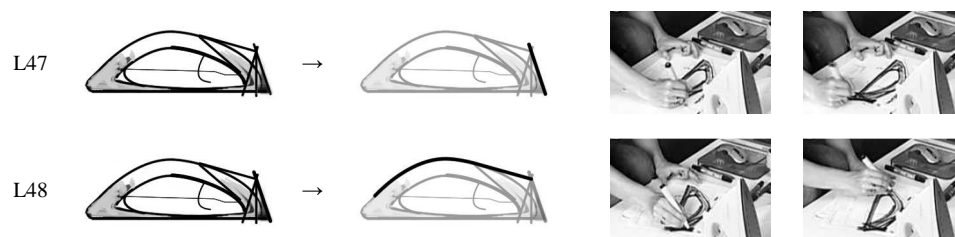


Lynn now returns to the side elevation, and also returns the side elevation itself to its original landscape format. The majority of her mark-making in this episode, and for the remainder of the protocol, is now directed toward defining the perimeter of the handle opening in side elevation.

Her first mark, in action L46, introduces a curved line which connects the upper and lower contours of the handle opening a short distance back from their endpoints.



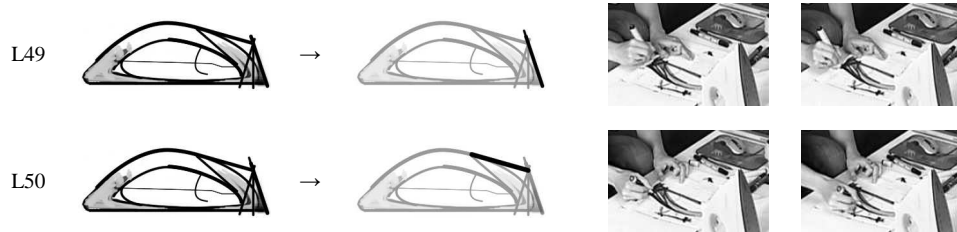
The next two marks, made in actions L47 and L48, are in contrast made on the outer contour instead, to reinforce the most recent heel rake modification and the connection of the existing elements that make up the upper profile.



Note that, between Actions L47 and L48, Lynn rotates the drawing again, although on this occasion it is only approximately fifteen degrees in an anti-clockwise direction. In the next action, when she returns to working on the heel line, the drawing will once again be rotated to portrait format and will remain in this orientation until the end of the protocol.

In actions L49 and L50 the new outer profile of the heel is reinforced once again. In action L49 this is achieved by drawing over the linear element of the mark made in action L38 which was also reinforced previously in action L47. Similarly in action L50 the line drawn initially in action L35, and previously reinforced in action L48 (where it was

combined with segments of the lines drawn in actions L11 and L12), is reinforced once more, although here the line is only used to reinforce the shorter line drawn in action L35, rather than the segment of the lines drawn in actions L11 and L12.



The division between the grip area of the handle specifically, and the forward part of the body generally, from the heel continues in action L51 where the line drawn in action L33 is overdrawn and reinforced.



Lynn shifts her attention to the forward area of the iron temporarily, to further define the underside of the grip area with a line identical to that made in action L28. In both these actions she selects a short segment of the line drawn in action L13, from the approximate high point of the curve to the intersection between it and the short curved line drawn in action L26. Action L52 is used to reinforce the handle grip area once more by drawing over it.



In action L53 she returns briefly once more to the heel area, reinforcing the linear element at top of the heel line (initially drawn in action L38) at its intersection with the upper profile line, previously drawn in action L35.



Lynn then spends the remainder of this episode concentrating on defining and refining the front and rear of the handle opening. To do this she employs a combination of both single linear, and compound shaded strokes.

Action L54 consists of a number of shading strokes to connect the curve drawn in action L46 with the lighter-toned shaded area laid down in actions L20 to L23.



She returns briefly to the line drawn in action L26. Although she draws over it once again, to reinforce it, she does so very lightly in comparison to previous reinforcing marks that have been made in other areas of the same drawing.



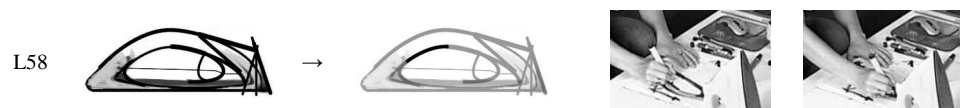
In action L56 a new profile for the rear of the handle opening is drawn with a curve that springs from the intersection of the curve drawn in L26 (and reinforced in action L55), the line drawn in action L13 (and reinforced in action L34) and the endpoints of the reinforcements of a segment of the line drawn in action L13 in actions L28 and L52.



Lynn then employs a compound shading action (in L57) to connect the curve drawn in action L56 to the shaded area drawn in action L54, and the curve drawn previously in action L46, at the forward end of the handle opening. Combined with the reinforcing strokes in actions L28, L34, L46, L52 and L54, plus the new curve drawn in action L56, the shaded area drawn in action L57 has now established about three-quarters the handle opening profile.



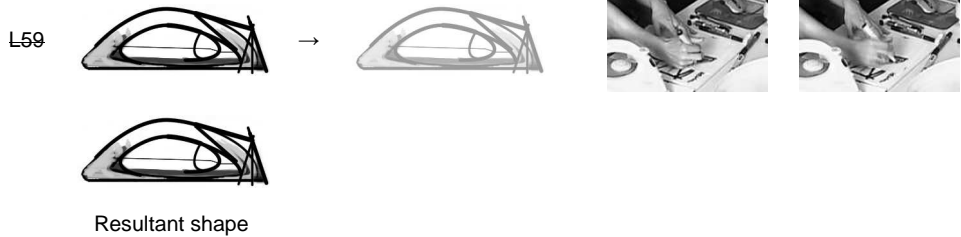
The final section of this profile is supplied by over-drawing the curve laid down in action L13 with a reinforcing line in action L58, completing the curve of the forward upper edge of the handle opening.



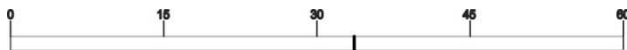
At this point Lynn lays down her pen and attempts to model the action of gripping a domestic clothes iron handle directly over the drawing of the handle, in the side elevation, as a form of ergonomic assessment.



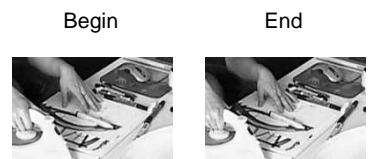
Immediately afterwards she picks up a pen and prepares to draw on the forward area of the iron, but abandons this drawing action before actually making a mark.



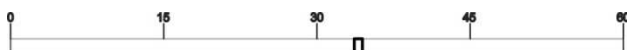
**4.4.10 Physical 'found' object: first episode (33:38 – 34:26)**



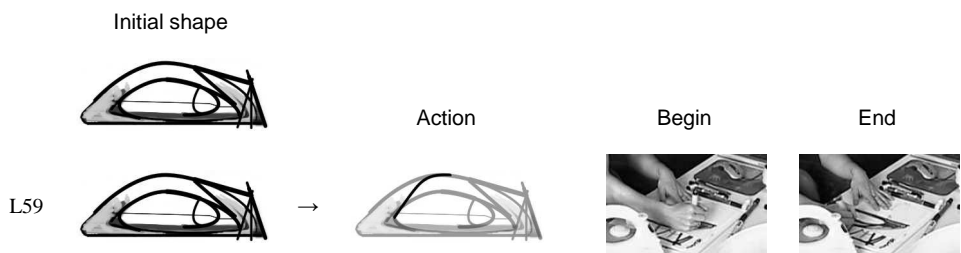
She now conducts another round of ergonomic assessment, but this time with a physical 'found object' in the form of an existing iron.



**4.4.11 Full-size side elevation: sixth episode (34:26 – 34:39)**



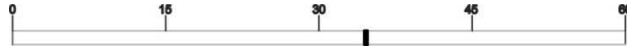
She returns to the side elevation once more, and draws a line (in action L59) which establishes a new division between the forward edge of the grip area, and the forward area of the proposed design. Although this line is not the final mark making act on the side elevation, it is significant in that it not only separates the front area of the body from the rest of the iron for the first time, but is also the final *shape* generating act of the protocol.





Resultant shape

#### 4.4.12 Physical 'found' object: final episode (34:39 – 34:44)



Lynn uses the iron again for a final check of its handle area.

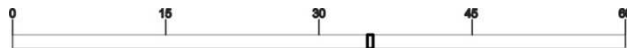
Begin



End



#### 4.4.13 Full-size side elevation: final episode (34:44 – 35:17)



Lynn finishes her mark making activity, and rounds off the entire protocol, by making a final 'annotative' mark. This appears to be similar in intent to her earlier emphasising of a functional aspect of the design, when she draws a spout of steam coming out of the iron. Here she appears to be referring to the requirement for ergonomic assessment contained in the design brief by drawing a life-size hand over the handle area of the side elevation.



Begin



End



### 4.5 Endpoint of the protocol

Lynn stops working on her design at 35:17 after producing a single sketch proposal each in plan and elevation. She states that, at this point, she would normally scan her sketches into her laptop and build a virtual three-dimensional representation over them. It was noted earlier, in section 4.3, that Lynn spent the first five minutes of her protocol preparing a file in Cobalt (a Mac based digital modelling program) for this purpose. As this

would occupy a further two to three hours, Lynn chose instead to draw her protocol to a close before completing her initial design proposal.

#### 4.6 Discussion and analysis

As was remarked on in section 4.1, Lynn's protocol, because of its relative simplicity and clarity, can serve as a useful introduction to this middle section of the thesis where the data gathered from four of the protocols is laid out. Furthermore, as it contains sketching activity only it can also serve as a datum to measure the subsequent and more representationally diverse protocols against.

In this protocol the effect of a participant's actions on their design representation is, for the most part, clearly visible in the still images taken from the video record that accompany each recreation of a design action. By laying out the author's recreations of design actions where they can be so readily compared to the visual record the verisimilitude of those recreations can be gauged directly by the reader for themselves. In later protocols, where they may be derived from more challenging material, this connection may not be so readily apparent.

It is also easier in Lynn's protocol to define an 'episode' of representation making activity: here, jumping from one instance of a design representation to another is always synonymous with a division between episodes.

The spatial degree of the representation making actions observed within these episodes is also consistent with the upper spatial degree of the representation itself, i.e., here Lynn works solely with lines and planes on a two-dimensional surface. In subsequent protocols, all of which contain episodes of either physical or virtual model making, the upper spatial degree of representation *making* actions observed in them is not so clearly consistent with the upper spatial degree of the representation.

Although Lynn's protocol contains less than thirty minutes of representation creation activity in total, and although she never moves beyond sketching in that time, an argument can be made that those sketches are still intended to lead to the creation of a three-dimensional representation. This is derived from anecdotal evidence gathered during, and immediately before the protocol. The first of these is the statement made by Lynn at 35:17

that she chose to stop working on her design proposal at this point as she would now normally move on to producing a virtual three-dimensional representation of it instead of continuing to sketch. This would of course entail her working for a period well outside the one hour time limit imposed by the design brief. This is confirmed by the observation that, in the period immediately before the start of the protocol, she loads digital versions of the supplied drawings into Cobalt, the digital modelling program she would have been used to build a virtual three-dimensional digital representation of her design proposal in if time had allowed.

There is further anecdotal evidence in the details of her workspace and working methods. Lynn was one of the participants in the initial round of interviews, undertaken by the author, to gather documentary evidence of the nature of form generation practices in the era of contemporary digital design. As became apparent then, as well as in this protocol and in a subsequent data collection exercise, her normal 'working space' is just a combination of her laptop and her sketchbook. The physical location of these two objects is largely irrelevant to her working methods. Her normal procedure therefore is to sketch a design proposal and then move directly to making a virtual three-dimensional representation of it on her laptop. It should be noted that although Lynn is capable of making a physical three-dimensional representation of her designs when she feels that this is necessary (the physical evidence of this was in the room where the protocol was filmed, in the form of plaster moulds and paper mock-ups of a vase design), she states that this is not part of her usual working practice.

As it seems reasonable to assume from these examples that Lynn's two-dimensional representation creation activity is genuinely intended to lead to a three-dimensional object, it also seems reasonable to assume that her sketching activity will be commensurate with that observed in the remaining three, more spatially developed protocols.

#### **4.6.1 Categorising design actions**

Two design representations were generated in the course of Lynn's protocol, a single instance each of a full-size plan view and a side elevation which she switches between frequently. The greatest number of consecutive actions in one representation (eighteen)

occurs in the second episode on the side elevation (described in section 4.4.3), while at the other end of the scale there were a number of episodes which contain only a single design action (described in sections 4.4.1, 4.4.4, 4.4.5 and 4.4.11). As there are only two design representations it should be noted that the single design action episodes were inevitably followed by a return to the previous representation.

Lynn's design actions in these episodes can be broken down into five distinct categories:

- Create a mark (draw a line, shade an area)
- Emphasise a mark (overdraw a line)
- De-emphasise a mark (overdraw a shaded area in a lighter, solid tone)
- Rotate the representation to a new orientation
- Annotate the representation

The first three categories contain the particular design actions which are directly concerned with generating shape. Fifty-nine of these were observed in total. Forty-six of these actions, *L1-L14*, *L25-L53*, *L55 and L56*, *L58 and L59*, were comprised of single linear strokes, twelve, *L15-L24*, *L54 and L57*, were shaded areas comprised of a number of contiguous strokes, and one, *L38*, combined both types of mark-making.

#### 4.6.2 Mapping categories of design actions against algebras of shapes

These three categories of design actions can in turn be mapped against one or more algebras of shapes. 'Create a mark (draw a line)', examples of which can be found in actions *L2 to L14*, *L26*, *L33*, *L35*, *L36 and L37*, *L39 and L46*, as it consists of lines on a plane belongs to algebra  $U_{12}$ :

$$\begin{array}{cccc}
 U_{00} & U_{01} & U_{02} & U_{03} \\
 & U_{11} & U_{12} & U_{13} \\
 & & U_{22} & U_{23} \\
 & & & U_{33}
 \end{array}$$

Figure 4-4 algebra  $U_{12}$ , lines on a plane

While ‘create a mark (shade an area)’, which can be found in actions L15 to L19, as planes on a plane, belongs instead to algebra  $U_{22}$ :

$$\begin{array}{cccc}
 U_{00} & U_{01} & U_{02} & U_{03} \\
 & U_{11} & U_{12} & U_{13} \\
 & & U_{22} & U_{23} \\
 & & & U_{33}
 \end{array}$$

Figure 4-5 algebra  $U_{22}$ , planes on a plane

The design actions found in the second and third categories, ‘emphasize a mark (overdraw a line)’ and ‘de-emphasize a mark (overdraw a shaded area in a lighter, solid tone)’ are contained in extensions of the  $U_{ij}$  algebras,  $W_{ij}$ , where the basic elements can have other properties associated with them (‘weights’).

These properties can be graphical ones, such as line thickness or tone. The line drawn in action L25, where an earlier line is overdrawn to increase its thickness (or, tellingly, its *weight*), is an example of an action carried out in the weighted algebra  $W_{12}$ , where the associated property is line thickness:

$$\begin{array}{cccc}
 W_{00} & W_{01} & W_{02} & W_{03} \\
 & W_{11} & W_{12} & W_{13} \\
 & & W_{22} & W_{23} \\
 & & & W_{33}
 \end{array}$$

Figure 4-6 algebra  $W_{12}$ , weighted lines on a plane

Further examples of design actions carried out in algebra  $W_{12}$  can be found in actions L30 to L32, L42, L43, L49 to L51 and L55.

The earlier line which was overdrawn in action L25, that drawn in action L1, while apparently contained in the algebra  $U_{12}$  is (paradoxically) also contained in the same  $W_{12}$  algebra as that drawn in action L25. While the line drawn in action L1 is the first to be drawn in the protocol by Lynn and, as such, should (by definition) be contained in the category ‘create a mark (draw a line)’, in this case it also belongs to the second category

'emphasize a mark (draw a line)' as it is employed here to increase the weight of a pre-existing line in the supplied side elevation drawing.

A different form of weighted algebra is also present in actions L20 to L24. Rather than line weight, the property associated with this algebra is tone. Furthermore, instead of being applied to lines, as in the previous example of a  $W_{12}$  algebra, this property is instead applied to planes in the algebra  $W_{22}$ :

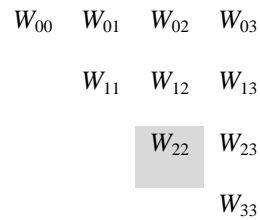


Figure 4-7 algebra  $W_{22}$ , weighted planes on a plane

These  $W_{22}$  algebras are found in the actions where Lynn uses a lighter-toned, solid shaded mark to modify parts of the original darker-toned, shaded areas in actions L15 to L19.

### 4.6.3 Decomposition and embedding of shapes

Lynn's actions, when laying down these shaded marks in actions L15 to L19, and her subsequent modification of them in actions L20 to L24 can be seen as decompositions of the elements created by these actions into new shapes.

The five darker toned marks made in actions L15 to L19, although broken down into individual elements by the pauses for assessment between them, can now also be perceived as a single continuous plane. These planar elements are not only fused to each other at this juncture, but also with the previously drawn linear elements to create a further decomposition (again into a single shape) but one which is now compounded of these two types of marks:

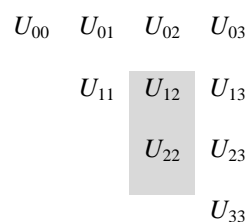


Figure 4-8 fusion of elements from  $U_{12}$  and  $U_{22}$

By comparison, the lighter-toned marks (made in actions L20 to L23) are applied to only part of the original darker-toned planar area rather than to the whole. This can be seen as an indefinite decomposition (by a 'weight' in the form of tonal variation) of the larger plane created by the fusion of the original marks. The final lighter-toned mark (made in action L24) practically unifies this larger plane but, in doing so, it now partially decomposes the single compound shape so far created into three new elements. There are now two linear elements, representing the inner and outer perimeters of the iron's profile, which remain lightly connected (by virtue of its lighter tone) by a third, planar element that spans the area between their lower regions.

A single linear element representing the outer perimeter of the iron had however already been in existence prior to this particular decomposition. This was generated in a similar fashion to the single darker-toned planar area created by the fusion of the marks made in actions L15 to L19, and here again fusion was created by adjacency. The lines drawn in actions L1, and L9 to L12, because of their tangential connections, could also be seen as progressively fusing into a single line, initially in an open curve but eventually converted into a closed one by the line drawn in action L12. Indeed, when viewed retrospectively, each of these lines can now be seen instead as decompositions of an implied, but previously invisible 'maximal' line describing this closed curve.

The single linear element representing the inner perimeter of the iron *is* new however. The lines drawn in actions L13 and L14, representing the upper and lower surfaces of the handle opening, initially did not meet at their forward end. The significance of the qualification 'practically', used when describing the unification of the larger plane by action L24, will now become apparent. Some of the darker-toned areas applied in actions L15 to L19 were not subsequently overdrawn in actions L20 to L24, and it is a remnant of part of this darker-toned area that now fuses the previously drawn lines (representing the handle opening) into a single, closed curve.

A similar decomposition of a larger maximal element into smaller elements can also be found in the linear elements of the design representation as well. Weights are again used but, instead of over-drawing complete lines, as in L1, L25, L30 – L32, L42 and L43, L49, L50 and L51, L55, here they are confined to tracing over a segment of a previously drawn

line, to emphasise that particular segment of the line and separate it from the remainder (in actions L28, L30 – again, L34, L40, L52 and L53, L58).

The line drawn in action L30 is notable in that it has a dual function, as it is both an over-drawing of a previously applied line (that drawn in action L4), and a decomposition of an apparently contiguous line compounded from the lines drawn in actions L4 and L5 (where the line drawn in action L5 has sprung tangentially from the endpoint of that drawn in action L4).

A third form of decomposition by weights, one that was only observed when Lynn worked on linear elements, entailed tracing over two or more previously (and separately) applied lines. This was applied to lines which were contiguous with one another, joining them into a new line that would then be perceived as a single element, in actions L27 and L48.

Two significant variations on this theme can be seen in the lines, and other marks, made in actions L29, L38, L41, L54 and L57. The first variation occurs in actions L29 and L41 Lynn starts over-drawing an existing line and then continues into a new line in one stroke, while the second can be found in actions L38, L54 and L57 where she uses *shaded* areas instead to connect previously unconnected lines.

#### **4.6.4 Quantifying and comparing design actions**

Goel's (2000) lateral and vertical transformations are used here to classify design actions by their generative potential. In the context of this enquiry vertical transformations can be seen as refinements, or developments of an existing shape (or form), while lateral transformations are the generation, or *emergence* of new ones. The frequency and nature of these emergent shapes (and forms) within each design representation can then be used to gauge the generative potential of each particular design representation.

The majority of design actions in Lynn's protocol can be classified as vertical, or developmental, transformations. Even the initial marks she makes in her side elevation sketch can be viewed as developments of an existing one. Her first action in the protocol, the mark made in action L1, is used by her in this case to reinforce one of the existing lines in the supplied side elevation drawing. The subsequent marks made in that sketch, in

actions L9 and L10, are effectively extensions of that line with tangential connections to it (although slightly set back from the end points of the line). The lines drawn in actions L11 and L12 are then further extensions of those drawn in actions L9 and L10, and once again with tangential connections between them.

As Lynn's sketches were made over existing drawings (the supplied drawings of the iron base in plan and in side-elevation) a case could be made for viewing some of her initial actions on the plan drawing (L2 to L5, L7 and L8), and subsequent actions on the side-elevation drawing (L13 and L14), as lateral, or generative, transformations of these pre-existing drawings. However, in an effort to bound this enquiry, this discussion is limited to those marks which were generated by the participant during the course of the protocol. The supplied drawings therefore, as they existed before the protocol commenced, can be considered instead as part of the environment that the protocol took place in.

There are however five examples of lateral, generative transformations to be found in Lynn's protocol (in actions L26, L35, L36, L56 and L59). The line drawn in action L26 is the first suggestion of a possible division, starting at the handle opening, between the rear portion of the iron and the remainder of the body. In turn the outer perimeter of this rear section is radically transformed by the combination of the lines drawn in actions L35 and L36. The line drawn in action L56 now transforms the division between the rear section and the rest of the body (created earlier in action L26) once more although, at first, it appears to merely be echoing that drawn in action L46 (which connects the upper and lower perimeters of the handle opening at the forward end). In contrast to this line though, which as a radius connecting these two lines might simply be viewed as a *parametric variation* of their connection conditions, the line drawn in action L56 also establishes a *new* line for the lower perimeter of the handle opening. The final lateral transformation is also the final design action of the protocol. This takes place almost as an afterthought in action L59 when Lynn quickly draws a line that separates the *forward* portion of the iron from the remainder of the body.

The lateral transformation described in action L35 is particularly interesting in that it was driven by a, so far, unacknowledged design representation: the design brief itself. Here, after re-reading the brief and noting that heel of the iron is specified to have a rake angle of ten degrees, Lynn breaks the implicit tangential constraint that she has applied to the lines

representing the outer perimeter of her design so far. Although the straight line drawn in action L35 springs tangentially from a point along the curved one drawn previously in action L12 (another example of an indefinite decomposition), its dangling end point is then only used as a focus, or 'hinge', to draw further lines through. The single lines and planar mark made in the subsequent three actions are simply developments, or vertical transformations of this new scheme.

The line drawn subsequently in action L36 does establish a rake angle of approximately ten degrees, but would probably result in an unstable configuration *and* would also require a large piece of the existing representation to be removed as well. It is at this juncture that Lynn rotates her sketch through ninety degrees so that the representation of her design proposal is now viewed in an upright position. The line that is drawn immediately after this, in action L37, *would* provide a base that would be stable in an upright configuration, *and* encompasses most of the section of the design representation that would have to be removed if the previous action had otherwise proved satisfactory, but does not provide any rake angle. The final compound mark made in action L38 starts off as a straight line that satisfies the requirements of a ten degree rake angle and a stable configuration, but does not connect satisfactorily with the rest of the representation. However, without pausing, or lifting her pen, Lynn immediately converts this into a compound linear / planar mark that does connect it to the remainder of the representation satisfactorily, with a number of contiguous shading strokes.

It should be noted that, although rotating her design representation through ninety degrees might alter Lynn's perception of the design elements contained within it, this will not affect the representational space itself, or alter the kinds of transformations that can be carried out on the design elements within that space. The perception of her design proposal may have been affected, but the representational constraints remain unaltered.

#### **4.6.5 Representational constraints**

While the side elevation and plan view sketches are separate instances of design representations they are, theoretically, descriptions of the same three-dimensional form. However, as they are drawn over orthogonal views of the base in side elevation and plan

view, the design elements contained within them are constrained within a two-dimensional design space. The representational constraints on these design elements are therefore similarly limited to transformations that can be applied in a two-dimensional space.

If it is assumed that the solution space that the designer is working in, or indeed their internal representation of the evolving design, is truly three-dimensional, then these orthogonal views can be seen to function as fixed viewpoints, or windows onto that three-dimensional internal representation. If Lynn is working from a complete internal representation it would then be possible for her to produce each view in isolation, perhaps even in a single episode.

Alternatively, if it is assumed instead that the internal representation is not as solidly defined as would be necessary to satisfy this extreme case, and that details of the design might be built up iteratively alongside the creation of an external design representation (which would of course incorporate the alternation between representations observed during this protocol), it might then be expected that each episode would be approximately equal in the duration and number of actions carried out in them.

However neither of these phenomena were observed during this protocol. An alternative thesis that does fit the observed sequence is that Lynn's actions, in moving rapidly between these two orthogonal views, could be seen instead as defining, and re-defining, her internal three-dimensional representation based on the results of her two-dimensional external representation making.

#### **4.6.6 Designed forms, or drawn shapes?**

The intended outcome of the design activity in this protocol is, ultimately, a three-dimensional object, yet all the design actions observed in it have been undertaken solely in two instances of two-dimensional design representations. While the intended three-dimensional outcome of this design activity (when mapped against the array of algebras of shapes) resides in the column containing  $U_{03}$ ,  $U_{13}$ ,  $U_{23}$  and  $U_{33}$ , all of Lynn's design actions have so far been carried out in either  $U_{12}$ ,  $U_{22}$ , or their weighted equivalents ( $W_{12}$  and  $W_{22}$ ):

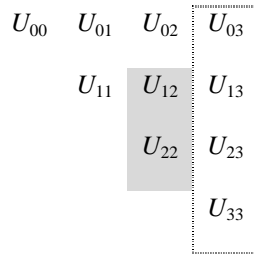


Figure 4-9 relation between Lynn's sketches and their intended outcome

The majority of these design actions, as they comprise making linear marks on a two-dimensional surface, are confined even further to a single algebra:  $U_{12}$ . Although these actions are themselves confined to  $U_{12}$  (as lines drawn on a two-dimensional surface) they are also, as the two-dimensional surface that these linear design elements are contained in also resides in three-dimensional space, a sub-set of algebra  $U_{13}$  (that of lines in three-dimensional space):

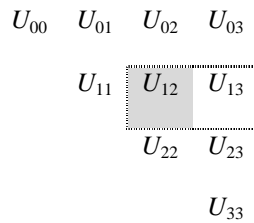


Figure 4-10 line drawings: a sub-set of three-dimensional space

This ambiguity, that shapes containing lines on a plane reside in  $U_{12}$ , but drawings themselves also exist in three-dimensional space (and furthermore are intended to represent objects in that three-dimensional space) is formalised in the three standard orthogonal drawing views which represent three-dimensional space (and the objects contained within it) by depicting them along the three spatial axes, labelled X, Y and Z. For the purposes of this discussion; the plan view is defined as a projection along the X axis, the side elevation as a projection along the Y axis, and the end elevation as a projection along the Z axis:

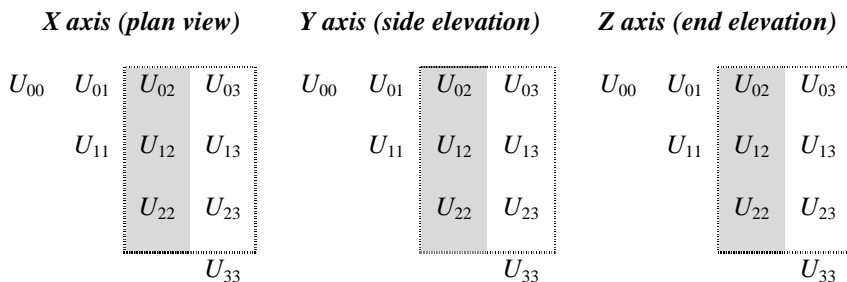
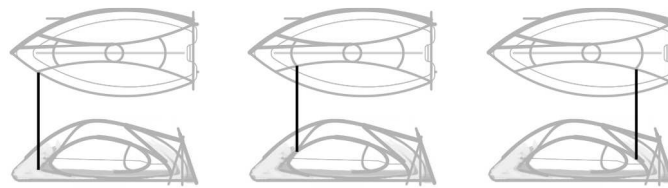


Figure 4-11 algebras of shape distributed across the three orthogonal views

Lynn's sketches therefore correspond with the first two arrays of algebras: X (plan view) and Y (side elevation).

When these two views are brought into alignment, if they do represent orthogonal views of the same three-dimensional form, they should show correspondences (depicting identical points in the three-dimensional representation) between them. Three areas of possible correspondence have been highlighted in Figure 4-12:



**Figure 4-12 three-dimensional consistency, or otherwise, between views**

The first (left-hand) illustration highlights the correspondence between the intersection of the line depicting the handle perimeter, in plan view where it meets the line depicting the perimeter of the foot, with the intersection of the two lines that represent the perimeter of the handle opening in side elevation. The intersection shown in the plan view suggests that, when viewed in side elevation, it should take place in line with the bottom edge of the iron, yet the side elevation shows it taking place at some distance above this.

It would of course be possible to resolve this apparent conflict by assuming that the sides of the body are vertical between the foot of the iron and the intersection, but to do so would mean contradicting three other pieces of evidence. Firstly, this area is actually part of the supplied model of the base which has distinctly sloping sides. Secondly, Lynn's hand motions (described in section 4.3 *Initial activities*) also traced out sloping sides when she morphokinetically modelled this area, and, thirdly, vertical sides would make a smooth transition from the angle of the front upper profile to the sides of the body very difficult to achieve. Similar discrepancies are also shown in the centre and right-hand illustrations. Here, although there is a distinct correspondence between the intersections of the lower ends of the split-lines in the plan view and side elevation, there is none at all between their upper ends.

These discrepancies suggest that Lynn's internal three-dimensional representation of her design is not fully realised at this point. The apparent correspondences between views owe more to forces in the external graphical representation rather than to a coherent and complete internal three-dimensional representation. The apparent two-dimensional correspondences between points, when they are considered only in two dimensions, are over-riding the three-dimensional constraints that might have come from a fully realised internal three-dimensional representation instead.

#### 4.6.7 Endnotes

When designers draw, are they drawing two-dimensional shapes or are they designing three-dimensional forms? The difficulties that arise when trying to match the intersection of the lines drawn in Lynn's plan view with their apparent intersections in her side-view suggest that, in this protocol at least, she is not designing a three-dimensional form. The apparent connections that exist between the two-dimensional plan and side views are impossible to resolve in three dimensions.

These apparent connections appear to owe more to forces in the graphical representation itself rather than the rigorous description of a three-dimensional form. Forces in the graphical representation were noted in sections 4.6.4, and 4.6.6, and those implicit tangency constraints, or forces in the graphical representation more generally, drove the initial version of the upper perimeter of the body.

As an example, the significance of the lateral transformation that came about in action L35 is that, while the earlier unsatisfactory design solution came about *because* of forces within the graphical representation itself (in the tangency constraint implicit in the lines laid down to represent the outer perimeter of the body), the subsequent satisfactory design solution was driven by forces outside the graphical representation (in the specification in the written design brief of a ten degree rake angle). Therefore, although sketching may generate lateral transformations, if these transformations are only properly applicable to two-dimensional shapes (possibly even suppressing the formation of a consistent three-dimensional internal representation) then they are, at best, taking time away from three-dimensional form generation and, at worst, actively interfering with it.

In subsequent protocols, as they contain both two-dimensional and three-dimensional representations, the relationship between these internal and external, and two-dimensional and three-dimensional representations is explored further.

The distinction between lateral and vertical transformations employed in this protocol will be used in these subsequent protocols to examine evidence of possible examples of form generation across representations of differing spatial degree. The following protocol, for example, as it contains examples of both two-dimensional and three-dimensional representation making, allows the frequency of the occurrence of these transformations in representations of differing spatial degrees to be directly compared.

