The Function of Value Engineering

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Abstract

Value Engineering (VE) techniques based on function have been the means to improved products and processes for several decades. It is a social design methodology that is usually episodic in application and often confused with narrow interests, such as cost cutting. This paper addresses the role, or function, of VE in a larger model of design practice to give insight into its use, non-use and misuse. The model identifies three levels of design practice, with a dual functional activity at its center. The process of innovative design shows tension between these functions. We conclude that VE is neither a different nor a sufficient way to design compared with more conventional analytical and synthesis techniques. It is rather a parallel and necessary process with different inputs and outputs.

1. Introduction

Product design is an unstructured but logical problem, for which successive iterations of synthesis and analysis eventually produce approximations to the desired results [Paz-Soldan 89]. Observation of design practice has led to a growing body of research that attempts to understand, or at least capture, what the designer does in the hopes of aiding the higher level design processes. Recent work has revealed some problems with the synthesis techniques adapted by designers in the mechanical domain [Finger 89]. The problem with our progress so far is that

> ". . . designers usually pursue a single design concept, and that they will patch and repair their original idea rather than generate new alternatives. This single concept strategy does not conform to the traditional view of what the design process ought to be."

The conceptual phase, from which the "single concept" arises, concerns the problem of coming up with new ideas or new solutions to older problems [Pugh 81]. Good conceptual design means innovation, and an innovative design comes about when one deliberately tries to create one [e.g., Cagan 87, Perkins 81]. For example [Bailey 78],

> "An engineer carefully studies power losses in a coal-fired plant and is able to increase efficiency by 0.1%. Another engineer studying the same

data conceives of the idea of using direct energy conversion to use the waste heat and increases efficiency by 5-10%."

Although the essential result (efficiency) is the same, the functions used to produce it are very different. The former approach represents optimization of a given functional model. The latter represents modification of this functional model. Processes for managing conceptual design and the process of innovation have long been described in the Value Analysis/Engineering (VA/VE) literature [e.g., Bytheway 65, Ruggles 71, Miles 82]. This method, when applie(by a small group of engineers is consistently effective in achieving focused conceptual design goals, such as attaining a given level of product performance, redesigning to reduce costs below a given threshold, etc. A study by the American Ordnance Association of a sampling of 2000 of its projects revealed improvements in cycle tim(reliability, quality and maintainability in excess of 60% [Prendergast 82]. That the process works is not debated, however, its application i typically episodic: A design team is brought together for a specific project and promptly disbanded when the specific goals have been achieved. (One may speculate that this irregular use of VE is due to th common practice of organizing design practice into domain-specific specialities.) Understanding the function of VE, how it is used, and its relation to traditional design methodology is the subject of this paper.

We have employed the terminology of the Society of American Value Engineers in dealing with representations of design practice [Sturges 90]. Specifically, *function* refers to largely domainindependent characteristics or behaviors of elements or groups of elements of a design. *Allocation* is the process or the result of assigning specifications and resources, and may be domain-specific. The *intent* of a design is expressed by the totality of its functional and aesthetic elements, their structure and their effects.

2. An Analysis of the Value Process

2.1 The Value of Function

The formal approach to functional analysis and design requires the representation of a design in the form of a *function block diagram* (FBD) through the process of *function logic*. Originally developed to stimulate design creativity [Bytheway 71], this systematic approach to the preliminary design process relies on early identification of design goals and describes them in functional terms. In essence, one must think in terms of what the product *does*, rather than what it *is*. One begins with a description of the basic function of the design. If the basic function cannot be accomplished by a single component, it is decomposed into several functions that collectively perform the function. These secondary functions may then be translated into components or recursively decomposed. The function decomposition process continues until we can map each function into a component or system that will accomplish it. Conversely, and existing set of functions are extracted from a given design through the Value Analysis process. This high-level form of reverse engineering results in the statement of the basic function and the reasoning structure which is already embodied in the product or process.

The general form of the FBD is shown in Figure 1. The function block (or node) contains a generic function descriptor (what is done) comprised of an active verb and a measurable noun. The VE approach employs a particular subset of classified verbs and nouns [Jakobsen 1990], namely, nouns which are either qualitative, quantitative, or conceptual, but not concrete. The verb set includes transformation and control, but excludes passive generation verbs such as "allow", provide", etc. The nodes to the left of a function node represent the reason *why* a function is included: a higher order function. The nodes to the right are functions describing *how* the function is performed: lower order functions.

The essential result of the function decomposition process is a reasoning structure relating each product or process function to the basic function of the design. This reasoning structure is deliberately divorced from specifications and constraints which would limit innovation or imply a particular problem solution. In fact, this stage of analysis invites the introduction of conflicting sets of requirements and unquantified parameters in the allocations attached to each function. This high level expression of the design also describes the conditions existing at the preliminary or conceptual stage of the design process. At this stage, so-called "wicked problems" are posed and addressed [Rittel 84]. A wicked problem is one for which design parameters are not merely undetermined, but are also indeterminate.

For example, the design of an engine to meet future emissions standards has elements of wickedness since the political climate, and EPA regulations, may change unpredictably between the start of the project and its completion.

The expression of a design in functional terms is no less valid, nor unique, when given a new set of indeterminate constraints as given last year's established ones. Retaining the functional model, in light of an instance of an allocation set, is valuable since it represents the intent of the design for that instance. This model is also ideally suited to developing variants in an existing design [Hundal 90]. Manipulation of the FBD creates alternative designs with a deep kinship to the original, but for which new allocation opportunities arise. It is when we determine the allocations attached to each function, i.e., quantify the limits of the design space [Kantowitz 1987], that we attempt to take the wickedness out of a problem. With a set of established constraints, design synthesis and optimization can often proceed to a finite set of alternative solutions [Westerberg 89]. As the problem parameters shift due to time and technology, new allocations are negotiated without changing the functional essence of the design.

2.2 The Function of Value

It is tempting to employ functional analysis on the practice of design itself. Models of engineering design practice derived from protocol studies indicate a diversity of views on design data

[Subrahmanian 90] and process [Ullman 88]. However, the evidence shows that almost all such activity occurs to the right of the rightmost scope line of Figure 1. Designers tend to work from interpretations of the lowest level functions expressed by their allocations. A broader view of design is needed to show conceptual processes. The model proposed in [Buchanan 85] more explicitly states the basic functions of the conceptual design process and the form of their allocations, viz.: ideas about products, the internal operational logic of products, and the desire to use products. Expressed in FBD form (in Figure 2), we find the basic function, Design Product, decomposed into three sub-functions, all of which must be present to assure product integrity. Of course, one may substitute Process for Product here with no loss of meaning. Recall that an FBD is not a flow chart, but rather a statement of activities in a process connected by reasoning which supports their existence.

Following [Buchanan 85], ideas about the product, in Express Character, are needed to articulate the overall quality, or *ethos*, of the product and is usually allocated to the process owners, or makers. For example, it expresses the differences between a plastic fork and a fine piece of sterling. The desire to use a product, in Express Feelings, is needed to anticipate and measure the user reaction, or *pathos*, to the product. For example, it expresses the differences in emotional experience between driving a sports car and a taxi cab.

The major activities in engineering and industrial design are found in the Express Behavior function, in which the term behavior applies to the internal operational logic of a product: the more physical expression of the artifact and its interactions with its user and its environment. At this level of expression, we recognize two sub functions. Determine Necessities expresses what the product is. This process of satisfying physical laws and practical constraints is carried out by reasoning, or *logos*, in a cycle of analysis and synthesis usually allocated to the engineering designer. The other sub function, Develop Possibilities, expresses what the product does. This process of satisfying functional desires and constraints is carried out through "true narration," or *mythos*, in a cycle of ideation and realization usually allocated to the industrial designer. Collaboration between these functions is evidenced, for example, in the Dustbuster™, which deliberately combines the (necessary) functionality of the vacuum cleaner with certain (possible) functional aspects of the telephone.

The model of design in Figure 2 expresses the dual nature of product specification development and the interaction between the talents which are usually allocated to these functions. Development of possibilities requires conceptualization of functions which give rise to a set indeterminate specifications and constraints. Together with considerations of character and feelings, the set may comprise a wicked problem. The VE process expresses the functionality of the design and attempts to allocate the specifications and constraints such that a literally reasonable set remains. Determination of necessities requires a fixed set of specifications, in that the relationships between parameters in the design space are defined, and the wickedness thus apparently taken out. Engineering analysis and synthesis may determine that a given set of specifications cannot be met by any artifact, in which case the possibilities would need to be reexamined. Indeed, a central element of the VA process is to deliberately require a design team to disqualify one or more given low-level functions (and their implied artifacts) of an existing design and develop other possibilities. This exercise avoids repeating old ideas.

In short, the VE process maintains the tension between concept ideation and realization by expressing both at a domain-free functional level. It also serves to develop specifications through the conceptual processes of function identification and allocation, such that the designer can proceed with traditional engineering analysis and synthesis.

3. Example

To illustrate the function of VE and its relationship to expressing the internal operational logic of a product, let us examine a familiar item which enjoys a continuing redesign process. The conceptual design of a chair is partially expressed in Figure 3 using the model of Figure 2 and the VE language. We have restricted our scope to the Express Behavior subfunction, therefore leaving out the logic which gives rise to specifications of aesthetics, weight, cost, intended point of use and customer. Recall that any of these allocations may be indeterminate and that the allocation process is a parallel design activity.

The necessary functions of the chair point to configurations of structural elements such as legs, back, and seat which interact to satisfy the functions Resist Forces and Resist Moments. A third necessary function, Distribute Loads, expresses the chair/user interface at the points of shared pressure. Each of these three functions (and there may be others) would be further decomposed by a deisgner until a collection of artifacts, constraint equations, or deterministic methodologies evolves which satisfy the allocations inherited by each lower level function from its parent(s). At this point the form is largely determined by the designer's interpretation of what a chair ought to be, or perhaps, what last year's model looked like. Innovation is a subjective matter, here, and indeterminate allocations will be decided by choice.

The possible functions of the chair express either old behavior which apparently satisfies no requirements or, better, new behavior which does not already exist. New functional behavior is developed by the designer in response to allocations from higher level functions, or from newly acquired understanding and appreciation of the present artifact. For example, the essential relationship between the user and his/her chair is explicitly expressible as the creation of postures. Selecting which parts of the user's anatomy is to be supported produces high level distinctions between different chair designs. Choosing to support the bottom and back of the user leads to a familiar class of designs (Figure 4), but choosing instead the bottom and knees of the user leads to an innovative class (at least at the time of its introduction) as in Figure 5. One can readily imagine the *mythos* of chairs ranging from bar stools to recliners by selecting postures suggested by support points.

Similarly, another essential relationship between the user and his/her intended use of the chair is explicitly expressible through the chair's function as a positioning agent. Selecting which user motions are aided or restrained produces high-level distinctions between alternative designs, e.g., piano benches, wheel chairs and barber's chairs. It is important to realize, here, that the creation of a product *mythos* is not to develop a taxonomy of existing chairs, but to develop *new* ones based on user criteria inherited from the higher level allocations of Figure 2.

At some point, the expressed behavior of the product is tentatively determined in sufficient detail to consider moving some *possible* functions to the *necessary* branches of the FBD for more detailed analysis and synthesis. The designer and/or the team suspends analysis of the indeterminate allocations and sets values for them anyway. This is the point at which the specifications originate and the wickedness of the problem is ignored.

Lest one conclude that VE reduces innovation to a mere combinatorial exercise, consider that the act of expressing the possibilities, the *mythos*, remains a creative and largely social task. The list of *other possibilities* in Figure 3 is, fortunately, unlimited and uniquely responsive to the needs of the total design.

4. Discussion and Conclusion

The functional model of design practice as expressed in Figure 2 helps explain the use, mis-use and non-use of VE. Innovation evidently occurs whether or not a designer is conscious of the process by which he/she explores new possibilities. The VE process may not explain the personal thought processes of the traditional designer. When applied as a discipline, VE contributes to innovation by satisfying functional desires and constraints while expressing concept ideation and realization (*mythos*) at a domain-free level.

When one restricts Develop Possibilities to cost allocation, one gets a new design at lower cost with no planned innovation. This mis-use may be good or bad depending on the larger issues of *ethos* and *pathos*. The maker designing only for lower costs may not serve a market desiring new functionalities. When one eliminates the development of a product *mythos*, one can only optimize a given design. Design becomes restricted to negotiating allocations. In both cases there is a large, structured engineering activity (*logos*), and the result may or may not be improved design.

On the other hand, there can be no artifact without the translation of low level functions and their allocations into domain-specific instances. Function logic is clearly insufficient to synthesize and analyze form, but that is not its purpose. We conclude that VE is neither a different nor a sufficient way to do design, but a parallel and necessary process for good conceptual design.

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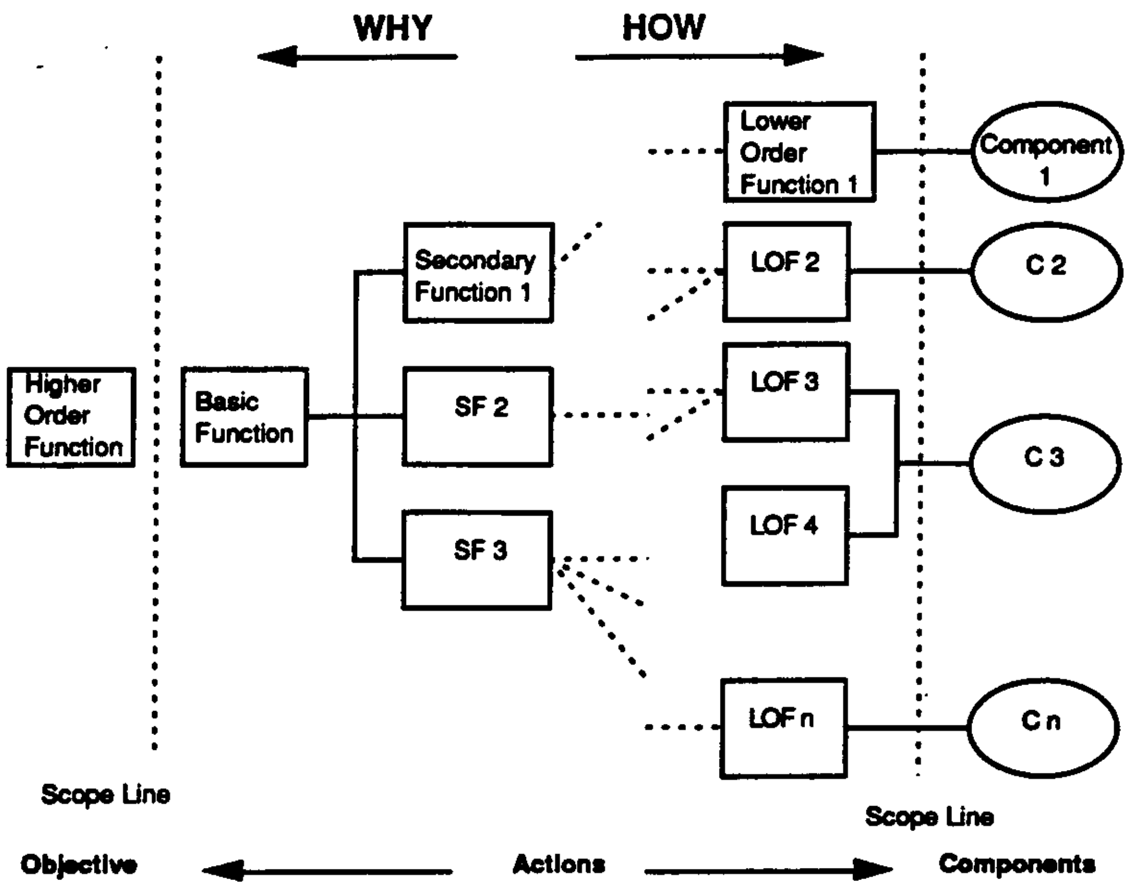


Figure 1. The General Form of a Function Block Diagram (After Ruggles 71)

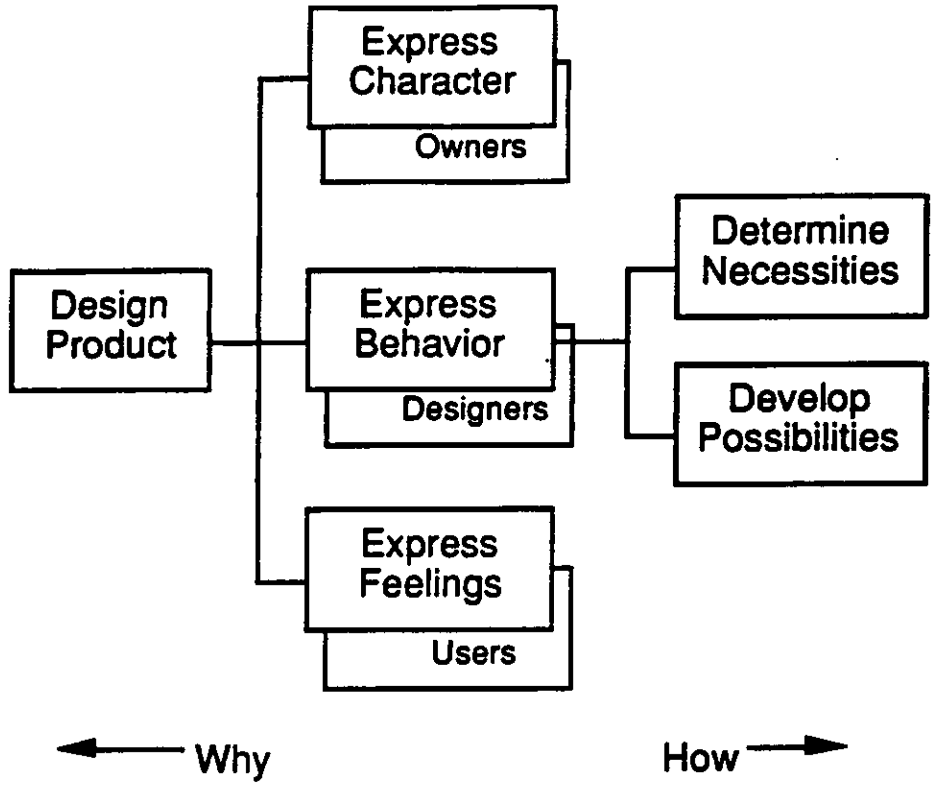


Figure 2. An FBD representation of design practice
(After Buchanan 85)

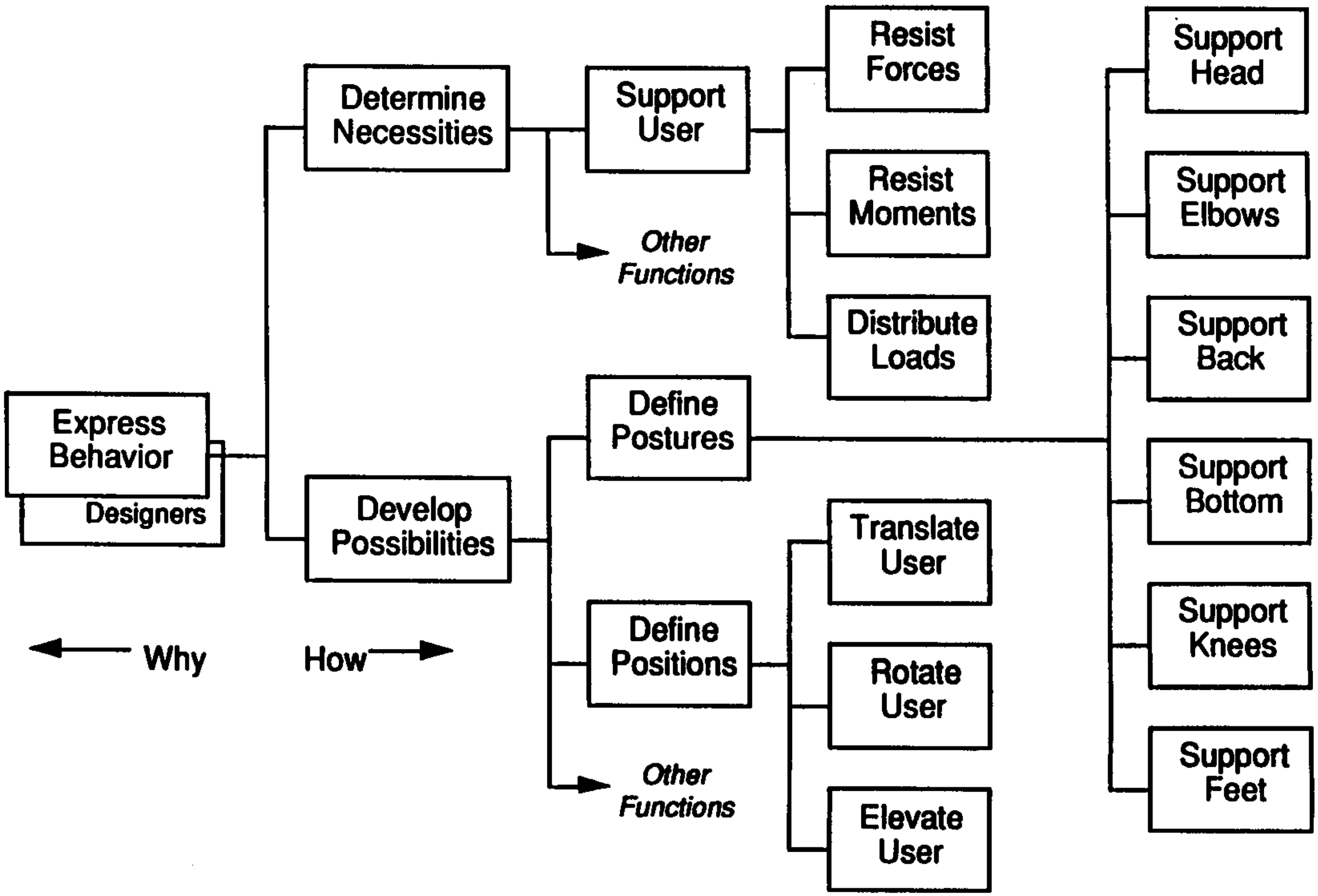


Figure 3. Partial FBD of a Chair

Figure 4. A Conventional Chair

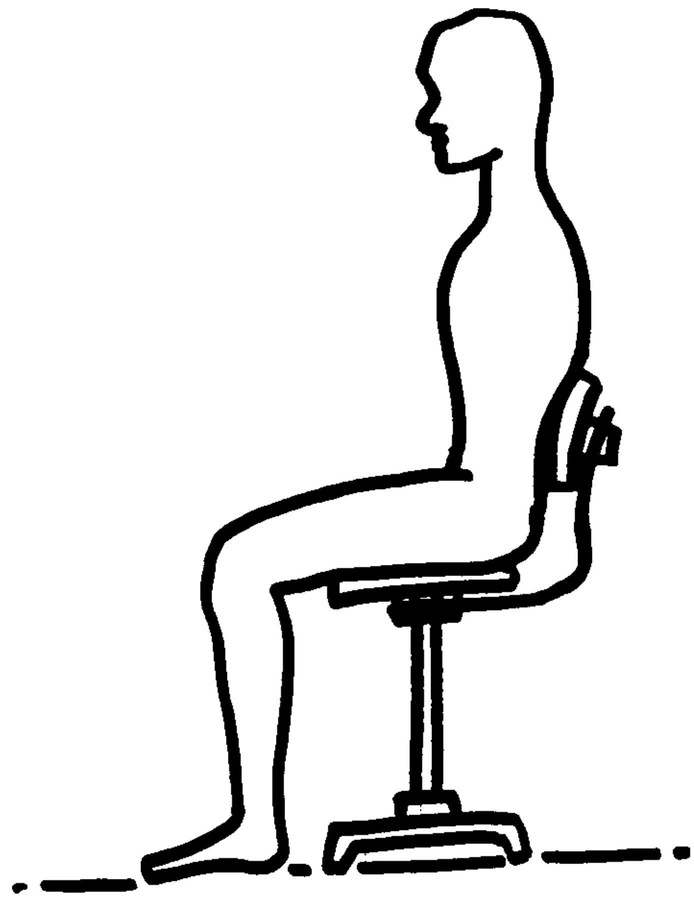
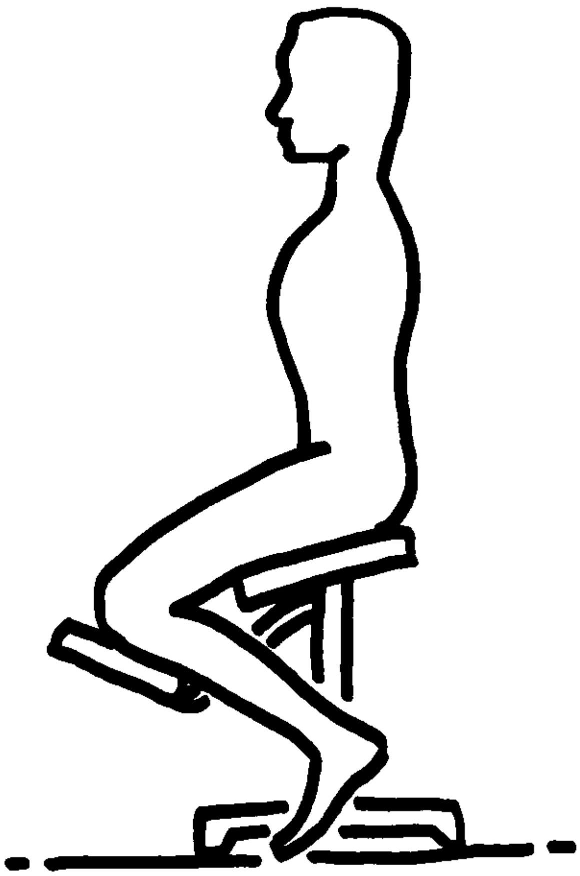


Figure 5. An Innovative Chair



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