CHAPTER 1

INTRODUCTION

The balance-scale task of intuitive physics has been of interest to developmental psychologists since its introduction by Piaget (e.g., Inhelder & Piaget, 1958). The task involves making a prediction about the state of a two-armed balance (i.e., tip or balance) based on a configuration of weights at particular distances from the fulcrum. The task is appealing because of age-related trends in performance, a U-shaped trend on a particular class of problems, and information salience effects. As the intersection between research on cognition, development, and connectionism grows, the balance-scale task has emerged as a benchmark problem for researchers attempting to model cognitive development (Shultz, Mareschal, & Schmidt, 1994; Shultz, Schmidt, Buckingham, & Mareschal, 1995).

The balance-scale task, like many tasks that have been used to study cognitive development, has two key characteristics (Siegler, 1996). First, the task as administered is not particularly familiar to children. Children have experienced the concept of balance but typically have not encountered this type of prediction task. The rationale is that by using novel problems, we can learn about participants’ naive conceptions and the strategies they employ when faced with unfamiliar problems. Second, it is among a class of tasks that involves the integration of information from two dimensions. Other examples include conservation of number, conservation of liquid, the slopes task, and the projection of shadows task (Siegler, 1976; Wilkening & Anderson, 1982).
The central thesis of this dissertation is that the balance-scale task is subject to the same inter- and intra-individual variability that is characteristic of the more familiar, everyday tasks studied by cognitive developmentalists such as math (e.g., Bisanz & LeFevre, 1990; Siegler & Crowley, 1991), reading (e.g., Perfetti, 1992), spelling (e.g., Varnhagen, 1995; Varnhagen, McCallum, & Burstow), time telling (Siegler & McGilly), and scientific reasoning (e.g., Kuhn, Garcia-Mila, Zohar, & Andersen, 1995; Schauble, 1990, 1996; Schauble & Glaser, 1990). The developmental course for these tasks has been described with the “overlapping waves” depiction of development (e.g., Siegler, 1995, 1996). At any one time, an individual has a variety of available strategies. Rather than sudden shifts from one qualitatively different way of thinking to another, change occurs through competition among strategies.

The balance-scale task, in contrast, has been characterized according to an older view of development: each stage of development corresponds to a single problem-solving strategy. Siegler (1996) has appealed to the unfamiliarity of the balance-scale task as a reason for why it is that a single, consistent strategy is observed for individuals at different stages of development. As will be shown from the review of literature in Chapter 2, however, many factors have been shown to affect the evaluation of individuals as using a single consistent strategy. In fact, it was the numerous criticisms of the rule-assessment method that prompted the research in this dissertation. Because rule assessments for an individual could vary with a number of different factors (e.g., task demands, the particular items used in the testing set), the method has been subject to criticism. Despite the growing
number of criticisms, modeling researchers using either production system or connectionist architectures have attempted to produce models that provide a good fit to the human data collected with the rule-assessment method. Moreover, modelers have used the rule-assessment method to evaluate the performance of their models.

In summary, the main argument advanced in Chapter 2 is that the numerous criticisms of the rule-assessment method have made the human data open to alternative interpretations. As such, computer models designed to capture the regularities in this data are also open to interpretation. Therefore, a new approach is advocated—an approach based on interpreting neural networks. This approach was taken to gain insight into the nature of how humans solve the task by first examining how neural networks solve the task and by examining the characteristics of the task.

In Chapter 3, the results of the network interpretation approach will be presented. Neural networks were trained to make balance-scale predictions and then the converged networks were subjected to four main interpretive techniques. A key finding was that the network was integrating the weight and distance dimensions and solving the task by approximating an additive function (although the mathematically correct method requires multiplication). An analysis of the problem space revealed that the majority of balance-scale problems could, in fact, be solved using an additive heuristic. This finding motivated an analysis of the characteristics of previously published test sets and an additional simulation in which neural networks were trained without the problems that cannot be solved using an additive heuristic.
In Chapter 4, predictions were derived from the analysis of the neural networks and the problem space analysis. In particular, predictions focused on the idea that performance measures (accuracy and RT) should vary as a function of where a problem is located in the problem space. The neural networks in Chapter 3 responded differentially to problems depending on location in the problem space. This prediction was tested with a group of undergraduates who were aware of the importance of both the weight and the distance dimension for making predictions, but who were not familiar with the mathematically correct rule (i.e., the *torque rule*, which involves a comparison of the product on the left side \[\text{weight} \times \text{distance}\] with the product on the right side). Torque difference was used as one rough index of location in the problem space (i.e., the absolute value of the difference in torque on the left and right sides). Torque difference was a good predictor of both accuracy and reaction time measures. Differences in accuracy and reaction time were found on the subset of items that can only be solved via the torque rule.

As mentioned, the criticisms of rule-assessment motivated a novel approach to studying the balance-scale task with respect to both neural networks and human performance. During the course of this research, it became clear that the criticisms of rule assessment should not be focused on it being an inadequate method of evaluation, but rather they should be focused on the *goals* of the rule-assessment approach. In Chapter 5, I argue that the goal of rule-assessment has been to determine the one consistent or modal strategy for individuals at different stages of development. Siegler (1996) has appealed to the *moderate experience hypothesis*, citing the unfamiliarity of the task as the main reason
why variability is not seen. That is, he has provided an explanation for why variability in strategy is not observed on the balance-scale task, when in reality, the cumulative evidence points to variability in strategy based on characteristics of the particular instance (e.g., the torque difference). This claim must be qualified, however, as the present results bear only on individuals who are aware that the two dimensions of the task must be integrated. The claim in general is supported by previous research in the literature in which variability in assessment was found with children of different ages.

Chapter 5 ends with a discussion of implications of the present research, suggestions for extensions to analogous developmental studies, and speculations about how current conceptions of development will influence future modeling studies.