NATURAL PATHWAYS IN THE PERCEPTION OF INVENTION SEQUENCE

By

STACEY L. DIXON

Bachelor of Science
Oklahoma State University
Stillwater, Oklahoma
1986

Master of Science
Oklahoma State University
Stillwater, Oklahoma
1988

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Thesis Approved:

Robert J. Weber

Thesis Advisor

Dick Green

William W. Rambo

Peter Moretti

Thomas C. Collins

Dean of the Graduate College

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Stacey L. Dixon

Oklahoma State University

Abstract

A quasi-historical approach, which studies perceptions of contemporary subjects regarding the development of existing related inventions, was used to gain a conceptual organization of inventiveness. Five experiments required subjects to rank four types of dishes (plate, bowl, cup, and glass) in the perceived order of natural development, rate the likelihood that the dish types originated from different sources, rate the likelihood that changes between dish pairs was motivated by food type, and identify heuristics used to move between dish pairs. Subjects strongly agreed in their perceptions of the invention process, suggesting that: 1) people think of related inventions as linked in sequential pathways, progressing from simple to complex artifacts, 2) organic origins are more plausible than inanimate origins for simple inventions, 3) the function an artifact is to serve is seen as a motivating factor behind its invention, and 4) the heuristics used in changes between two related inventions are readily recognizable.

Natural Pathways in the Perception of Invention Sequence

The study of the process of invention has become of increasing interest (Jones, 1970; Simon, 1981; Weber & Dixon, 1989; Weber & Perkins, 1989). At least two pragmatic reasons exist for the increased interest: We need better ways of conceptualizing and teaching about invention, and any knowledge gained through research on how to become a better inventor may be applied to increase the quality and the quantity of known inventions. With the rise in competition between the United States and other countries to present original ideas to the world market, there is a growing need for us to increase our production of patentable inventions. The U.S. Patent and Trademark Office defines patentable inventions as new <u>and</u> useful <u>and</u> nonobvious (U.S. Department of Commerce, 1985). Given the recent attention to national productivity, the study of invention is now both necessary and timely in order to create a "bridge or interface between the worlds of technology and cognitive science" (Weber & Dixon, 1989).

Psychologists in particular are entering into the investigation of invention. One reason for this specific interest is that the study of invention offers a very applicable and concrete way to study two other important psychological processes: creativity and problem-solving. In the past, cognitive psychology focused on issues such as creativity and problem-solving in order to research the act of creating something new and useful (Weisberg, 1986). Historically, however, researchers have had difficulties in pursuing these routes of studying creative mental processes, and they have often considered highly artificial problems. The study of invention helps us to overcome those difficulties by supplying important real-world problems.

Difficulties in the Creativity and Problem-Solving Literature

One difficulty encountered throughout the literature is that the term "creativity" is notoriously difficult to define (Weisberg, 1986). The "genius" view of creativity is accepted by some. This view assumes that a very few creative persons exist who have extraordinary talents that spring inexplicably from them in great creative leaps. Another approach to defining creativity is the "nothing new" view, espoused by John Watson (1968). This definition involves the assumption that there truly is "nothing new under the sun," and that creative acts are simply generalizations of one or more old ideas _or_ that new ideas are simply random combinations of responses" (Watson, 1968). A more modern view is that "creative problem-solving involves a person's producing a novel response that solves the problem at hand (Weisberg, 1986). Due to this definitional difficulty, researchers investigating creativity and divergent problem-solving seldom agree upon exactly what process they are studying.

A second problem is the means by which researchers have trained people to think in creative ways. The major training tactic has been "brainstorming" (Bouchard, 1971; Bouchard & Hare, 1970; Dillon, Graham, & Aidells, 1972; Dunnette, Campbell, & Jastaad, 1963; Osborn, 1953). The brainstorming technique attempts to enhance creativity and problem-solving by stressing "copious ideation" and by withholding judgment until many ideas are produced (Osborn, 1953). This technique involves the assumption that critical thought during idea generation decreases creative production. Contrary to this assumption, several studies indicate that when subjects evaluate and eliminate bad ideas during the generation process, they produce more high-quality solutions than their brainstorming counterparts (Gerlach, Schutz, Baker, & Mazer, 1964; Johnson, Parrott, & Stratton, 1968; Weisskopf-Joelson & Eliseo, 1961). These results address the need for methods of training people both to generate and to evaluate ideas to filter out the ridiculous and implausible in early stages of production.

A third problem encountered in past research on creativity and problem-solving is low generalizability. For example, results from divergent thinking tasks (which encourage thought similar to free-association to generate as many ideas as possible, like brainstorming) and problem -solving tasks often have low generalizability to important problems. Mansfield and Busse (1981) showed that performance on divergent thinking tasks is unrelated to scientific creativity. In other words, the most creative scientists are not the persons scoring highest on divergent thinking tests.

A fourth, and more general, problem is that the methods used to teach creativity and problem-solving are not consistent with research findings. To date, most of the teaching on invention and creativity is largely intuitive with little supporting data. For example, Osborn's (1953) brainstorming tehcnique is widely used in public schools and major corporations across the U.S., even though scientific studies show that brainstorming often results in the production of fewer high-quality ideas than more evaluative methods of idea generation (Weisskopf-Joelson & Eliseo, 1961). Thus, in addition to teaching people to produce more ideas, we need to devise ways to teach people to become better critics of these ideas. Through systematic research, we may find more concrete and generalizable principles for teaching creativity than those found previously in the literature. Applicable heuristics (principles helpful in generating ideas), analagous to those in the problem-solving literature, may aid would-be inventors in better generating and evaluating their ideas.

Recent Studies on Invention

Historically, both psychologists and non-psychologists have studied invention in the context of design (Alexander, 1964; Jones, 1970; Norman, 1988; Simon, 1981). Design is largely the act of improving upon already existing inventions. This definition differs from the "new, useful, and nonobvious" definition of invention cited earlier. However, for the purpose of this paper, invention will be defined so as to include design as well as the creation of original artifacts (Weber & Dixon, 1989; Weber & Perkins, 1989).

In the psychological literature related to invention, recent studies include: a) the investigation of historical cases of inventions, such as the telephone (Gorman & Carlson, 1989; Langley, Simon, Bradshaw, & Zytkow, 1987); b) the use of architectural inventions of Neolithic peoples to understand their geometrical knowledge (Cowan, 1988); and c) the outlining of interesting methods for applying heuristics to invent artifacts and ideas (Weber & Dixon, 1989; Weber, Dixon, & Llorente, 1991; Weber, Moder & Solie, 1990; Weber & Perkins, 1989). While these studies are rich in concept and thought-provoking information, they lack systematic study of their generated hypotheses and heuristics. Clearly, one step in discovering the mental processes underlying the creative act of inventing is to test contemporary subjects' perceptions of some simple heuristics which may aid in inventing.

Key Concepts to Understanding Invention

In this study, a quasi-historical approach to understanding inventions will be used. Such an approach to the study of invention equips the psychologist with an extensive database created by the tracks of past inventive minds (Weber & Dixon, 1989; Weber, Dixon, & Llorente, 1991; Weber & Perkins, 1989). Instead of using retrospective accounts of established inventors, which would require the questionable assumption that an important invention springs from a single mind, the scientist working from a quasi-historical approach begins with a collection of known inventions. By using a family of simple artifacts, such as different types of dishware, to investigate fundamental changes along a given invention pathway, the researcher is able to use the accelerated products of aggregate minds to understand possible heuristics that drive invention. The idea is that larger changes are easier to see than small changes. In addition, when the heuristic processes that drive an invention along its pathway are found, they can add to the knowledge of a single inventor; that is, they become normative principles that take residence in the mind of the individual inventor.

Notice that within this approach, strong historical claims are not being made. The historical record is too fragmented. Instead, a conceptual ordering is sought. The situation is analogous to that of Euclid, who collected geometric truths and then attempted to systematize them. History was a useful guide, but it was the conceptual system, its organization and clarity, that was ultimately the goal. The same emphasis is present here. Whatever the actual history, if related inventions (such as different types of dishes) can be conceptually ordered, a way is provided for thinking systematically about an important class of inventions. We are all familiar with this process. It is the path from disorganized and unsystematic discovery to the coherent organization of knowledge in a textbook. The difference is that textbook organization is often the work of a single author. Here the goal is to determine more systematically the natural mental organization or path of a wide group of people.

When using a quasi-historical approach to study inventior the following assumptions must be made:

1. Everyone is an inventor at some level of sophistication. Invention is not a unique process experienced by only a few genius minds. Thus, we can study the perception of invention in the average person.

2. The mental processes of people today are not fundamentally different than they were ten thousand years ago. Therefore, people today can make judgments about very old inventions.

3. Judgments are easier to make than productions. This assumption is certainly true in areas such as music, where a

listener can be a very sophisticated critic yet may not be able to play an instrument at all. So, perhaps contemporary people can readily judge the order of steps between invention states and recognize candidate heuristics used in moving between these states, even for very old inventions. The reader must keep in mind that ordering steps and recognizing heuristics is qualitatively different form the act of inventing, which involves weeding out irrelevent factors and disregarding distractions in order to produce something new.

In order to aid the reader in understanding the link between contemporary subjects' perceptions about inventions and the actual historical record of known artifacts, two important concepts of the quasi-historical approach to studying invention, frame description and gain analysis, are now discussed.

Frame Description. A frame description is one method of generating discussion about an artifact in order to better understand the invention and to produce ideas for possible "next steps" along the invention pathway (Lenat, 1978; Minsky, 1975; Weber, 1987; Weber & Dixon, 1989; Weber & Perkins, 1989). A frame description consists of a representational framework of an object, action, or idea. This skeletal frame contains slots, or characteristics which define the object, such as attributes, relations, or procedures. The values of the slots are instantiations of these defining characteristics.

It may be useful for the reader to visualize a frame description as much like entries in a bookkeeper's ledger. The title of the page in the ledger, such as "Record of Expenses," is the idea to be described. The names of the rows, such as "Gasoline" or "Rent" are the slots. Instances of each slot may be entered as a date, an amount of money, or the name of the creditor to whom the money was paid.

Insert Table 1 about here

Table 1 shows a frame description for a cup with a handle, one of the pieces of dishware used as a stimulus object in the present study. The slots are italicized words with the intitial letter capitalized, while the values are in lowercase letters. This frame description provides a good starting point for analyzing the invention of the cup.

It is important to note that a frame description is only one of many possible ways to represent knowledge about an artifact. Other conceptual aids, such as Gorman and Carlson's (1989) "mental models", may also prove to be useful. They described a mental model as an incomplete, unstable mental prototype "which incorporates [the inventor's] assumptions about how a device might eventually work." While such underlying mental processes quite likely do occur and are highly interesting, the authors admit that mental models are often "hazy" and difficult to define. The frame description, while possibly not as close as the mental model to the inventor's actual conceptualization of an artifact, certainly has more clearly-defined boundaries within which historical examples and anonymous inventions fit readily. The mental models approach requires detailed knowledge of the inventor's thought processes, a requirement that cannot be satisfied by most inventions. Thus, the frame description is a better fit for the analytical study of the very old, anonymous inventions studied in this paper.

Two other interesting points are presented by Gorman and Carlson: 1) an inventor might consider competing mental models to solve a problem and 2) "mental models can be nested within one another." When mental models are nested, the inventor may have "an overall mental model of a device and mental models. . .of components of that device." Frame descriptions of similar inventions, too, can be compared by an inventor as to which best solves the problem at hand, which is most efficient, etc. They can be nested within one another or overlapped at one or more slots. Further discussion of how separate frame descriptions may be interrelated will be presented later in this paper.

Gain analysis. Weber and Dixon (1989) used a historical approach to study the principles that drive inventions along their pathways. They examined the pathway of the invention of sewing by a means of <u>gain analysis</u>. Gain analysis involves:

1. Identifying different states on a given invention path. Possible precursor states to an existing invention may be found by parsing the invention into its components and constructing a frame analysis of the parts. A search of the historical record for precursor inventions is then made to find artifacts which lend evidence that improvements were made to arrive at the existing invention.

2. Examining the differences between the invention and its precursors through a frame analysis of each artifact.

3. Arriving at possible heuristics to bridge the differences between the invention states.

4. Generalizing the heuristics to different inventions.

In the present study, a modified gain analysis procedure will be used to investigate the perception of natural pathways between different states of an invention set, dishware. If subjects are able to perceive a pathway between different types of dishware in Experiment 1, then following experiments will look for possible heuristics to explain the movement from one dish type to another. If such heuristics are deemed applicable by the subjects, then a discussion of the possible mental processes underlying the use of the heuristics will follow. Generalization of the heuristics will be addressed through experimentation and discussion.

Objectives of the Present Study

The continued usefulness after thousands of years of such basic inventions as the wheel, the needle, and the knife underscores the potential importance of the mental processes involved in inventing them. The present study continues within this context. The important invention of dishware will be compared to the invention of digging tools. Dishware was chosen as a point of reference because of the practical importance and long history of its use and because of the simplicity of changes in its invention pathway. For example, when moving along a hypothetical pathway from a plate to a bowl without handles, one may transform along a single dimension, depth (see Figure 1). Basic digging tools, too, undergo simple changes along their hypothetical invention pathway. Figure 2 shows that when moving from a square shovel to a snow shovel, the most obvious change is that the width of the scoop increases. Other changes shown in the line drawing--such as the increased length of the shaft, the change in the shape of the blade, and the increased width of the handle--are also basic transformations.

Insert Figure 1 about here

Insert Figure 2 about here

In Experiment 1, variations in dishware (such as a cup, a bowl, a plate, and a drinking glass) are ranked in the perceived order in which subjects believe the dish types to have been invented. A duplicate study involving variations in digging tools (such as a scoop without a handle, a spade, a square shovel, and a snow shovel) is also run in order to generalize any observations of a possible natural order of developmental steps, or a natural pathway, between similar inventions. It is important to note that the perception of order in sets of dishware and tools is NOT obvious to the examiner prior to the experiment. Thus, the preselection of the dish and tool types presented was made without the intent of enhancing the obviousness of a particular ordering.

Experiment 2 focuses on possible precursors to the dish types used in the first experiment. Four precursors are considered. Subjects are asked to rate the likelihood of each dish type having sprung from four precursor categories: human body parts, animal parts, plant parts, and inanimate structures. Experiment 3 looks at the plausibility of pathways between pairs of dishes (e.g., how likely was the move from a plate to a glass) and pairs of digging tools (e.g., how likely was the move from a square shovel to a snow shovel). The twelve possible pairs of the four dishes and the twelve possible pairs of the four digging tools used in Experiment 1 are rated as to their plausibility that dish A came before dish B (or tool A came before tool B) in the historical record. These plausibility ratings are qualitatively compared to the expected results based on the rank orderings of the dish types and tool pairs in Experiment 1. Thus, if a plate was ranked before a glass in Experiment 1, one would expect the plausibility ratings in Experiment 3 to be higher for the dish pair "Plate to Glass" than for its opposite, "Glass to Plate." The dish and tool pairs are also used in Experiments 4 and 5.

Experiment 4 searches for motivating factors in the transformations between dish pairs (e.g., changes from a bowl to a cup with a handle). Subjects are asked to rate the likelihood that different food types (hot/cold, solid/liquid) stimulated the moves between dish pairs. Finally, Experiment 5 searches for the subjects' knowledge of the heuristics used in transforming dish A (e.g., a plate) to dish B (e.g., a bowl). The results from the dishware heuristics are compared and contrasted with the subjects' ability to identify heuristics used in transforming one digging tool (e.g., a spade) to another (e.g., a snow shovel).

Experiment 1: Perceived Pathways

This experiment searches for evidence of people's perceptions of a natural pathway between related invention states. The idea of a natural order for mental processes is not new to the field of cognitive psychology (Barsalou & Sewell, 1985; Bower, Black & Turner, 1979; Schank & Abelson, 1977). Researchers investigating the representation of knowledge of routine actions, such as eating in a restaurant, have shown that such actions are organized in memory in the form of scripts, or typical sequences (see Table 2). For example, Bower et al. (1979) found substantial agreement between subjects on the order of action in familiar scenes. They also found that subjects recall the more typical sequence of a scene over a scrambled presentation sequence.

Insert Table 2 about here

Scripts may be conceptualized in a slightly different manner using a frame analysis. Table 2 shows a frame description of the restaurant script (Schank & Abelson, 1977). The scenes involved--entering, ordering, eating, and exiting--are represented as procedure slots. Therefore, the values of the slots are the actions included in each scene. For example, in the "eating" scene the action values may be: a) cook gives food to waitress, b) waitress brings food to customer, and c) customer eats food. Note that this frame description is quite similar to the individual frame of the cup in Table 1, but the script frame has the added feature of <u>sequential</u> values.

Perhaps there is this element of sequence within the frame description of a single invention and/or between the frame descriptions of related inventions? For example, in the frame description of the cup in Table 1, are there sequential links between the instances of the slot labeled <u>Precursor Inventions</u>? One could argue that the cupped hand is a precursor of the half shell. The half shell then may lead to a bowl-shaped artifact. After adding a handle, this hypothetical sequence of the invention pathway nears the present state of the cup.

Likewise, does the entire frame for the cup fit within a natural order of the slot contents labeled <u>Related Inventions</u>? For example, does the bowl precede the cup in this invention pathway, and/or is a drinking glass without a handle a precursor or a successor of the cup? If these related artifacts were invented in some sequence, then we may assume that there was also a natural order to the cognitive processes involved in modifying the cup and creating its related inventions.

If there is some perceivable order to the processes underlying a path of simple inventions, then subjects should be able to agree in rank ordering such artifacts as to which came first, second, and so on. In Experiment 1, subjects are asked to rank different types of dishware in the order of perceived invention. If a natural pathway is perceived, then a particular dish should be ranked in one order more often than others.

The obvious alternative to such a perceived natural pathway would be no order, or random changes between invention states. Here we would expect each dish to appear in each position roughly the same number of times. Such a random distribution of the dish types would lead to the conclusion that all dishes have completely independent origins, at least as perceived by contemporary subjects. In order to generalize the findings for or against natural pathways, results of the dishware rankings are compared and contrasted to the subjects' rankings of four types of digging tools in the perceived order of invention.

Method

Subjects. Subjects were recruited from an introductory psychology course at Oklahoma State University. Thirty-six subjects for the dishware rankings and thirty-eight subjects for the digging tools rankings were given extra credit for their participation in this study. Other means of obtaining extra credit were available.

Procedure. In the dishware study, subjects were given a pencil and paper task which showed four dish types (a plate, a bowl, a cup with a handle, and a drinking glass shape) in a randomized order. They were instructed to rank the four artifacts in order of the relative time of invention (see Appendix A), and they were asked to give brief explanations for their rankings. The purpose in collecting the explanations was to obtain a qualitative understanding of how people view transitions from one invention state to another. The explanations were qualitatively classified by two different judges and then analyzed. A percentage of agreement between the two judges was calculated for each of the classifications.

To produce generality, another study employed a very different class of stimulus materials. Four types of digging tools (a scoop without a handle, a spade, a square shovel, and a snow shovel) were also presented as stimuli to a separate group of subjects (see Appendix B).

Results and Discussion. Table 3 shows that most subjects ranked the plate as the first of the four dish types invented, with the bowl as second, the glass as third, and the cup as fourth. The apparent agreement between subjects on this pattern of dishware development is quite striking and strongly supports the hypothesis that subjects are able to perceive natural pathways between related artifacts.

Insert Table 3 about here

The reader will notice that the rankings for the plate and the bowl are somewhat similar. This similarity may be due to the greater availability of naturally occurring models for the plate and the bowl than for the more derivative cup and glass. Too, both the plate and bowl are quite simple inventions with the only major structural difference between them being depth. Thus, if subjects ranked the four dish types on the basis of simplicity or most similar to naturally occurring forms, then the plate and the bowl would likely vie for the first two positions.

In the digging tool study, subjects also exhibited an overall preference for one pathway between the tools, with the scoop first, the spade second, the square shovel third, and the snow shovel fourth (see Table 4). Here the differences between each of the rankings show that overall the subjects clearly agreed upon the ordering of the tools.

Insert Table 4 about here

Subjects' responses to the four questions regarding the reasons given for ranking the dishware and the digging tools in the orders shown above (see Appendixes A and B) were qualitatively analyzed. Many of the subjects explained their ranking by using a heuristic of moving from the most simple invention towards the most complex. For example, a plate is obviously the most simple instance of the dish types with only two dimensions and no handle. A bowl adds the dimension of depth, a glass increases the depth and decreases the width, and a cup changes the depth and width and adds a handle. A simlar pattern of "simple to complex" reasons was given for the digging tools. Other reasons given for the rank orders include: adding parts or dimensions, increasing size, moving from general to more specific functions, and increasing the efficiency of the invention In order to quantitatively analyze the subjects' reasoning behind the rankings, the first reason given by each subject as to why a particular invention was ranked in the first position was categorized by "type of reason" (see Tables 5 and 6). A second judge also categorized the response by type of reason, and the percentage of agreement between the two judges for the categories in the dishware study was at or above 75% for all categories, except for Most Specific (71% agreement) and Most Natural (60% agreement). In the digging tools study, the percentage of agreement between the two judges was at or above 85% for all categories, except for Most Natural (71% agreement).

Insert Table 5 about here

Insert Table 6 about here

In the dishware study, some of the responses within the categories of "Simplest" and "Flattest" appeared to overlap. For example, several subjects who gave simplicity as a reason for ranking the plate in the first position elaborated their response with the reasoning that the plate was the flattest dish type (e.g., "It's basic. . .just flat"). Other subjects gave similar responses, only in a reversed order (e.g., "It's just a flat object. . .the simplest"). This finding lends further credence to the hypothesis that most people view the natural pathway of dishware as moving from simplicity to increasing complexity. However, the similar categories were not collapsed together because not all responses within one category were judged to be clear elaborations of another category. Thus, collapsing across such responses would possibly bias the date in favor of the "simplicity" hypothesis.

An apparent overlap of some categories in the digging tool study was also found. Examples of the categories of "Most Primitive" (e.g., "It's crude"), "Simplest" (e.g., "It has nothing to it. . .it is not as advanced as the others"), and "Most Natural" (e.g., "Most natural source at the time") all seem to be stating that the tool ranked first lacks complexity. Here again, though, these categories were not combined to prevent any bias in the data. This finding shows, however, that the heuristic of moving from simple to more complex artifacts along an invention pathway is generalizable to some pathways outside of the development of dishware.

In order to test the null hypothesis that there were no significant differences between the frequency of responses in the type of reason given first, a chi-square analysis was performed in both studies. In the dishware study, there were significant differences in the distribution of the types of reasons, $\chi^2(6)=32.06$, $p < .01$. A separate chi-square was also performed on the first reason for digging tools, with $\chi^2(4)=15.95$, $p < .01$. Here, too, there was a significant difference between the expected and observed frequencies of the different types of reasons (see Table 6).

Experiment 2: Origins

The results of the previous experiment support the notion that there are recognizable natural pathways between invention states and that contemporary subjects are able to agree upon reasons for such natural order (e.g., the move from simplicity to complexity). Given that information, the following question arises: Do contemporary people agreeupon the plausibility of an origin or a class of origins for related artifacts, such as dishware?

The main purpose, although certainly not the only purpose, for the invention of dishware is to contain different substances. Johnson (1987) suggested that the idea of containment sprang from the observation of the human body's ability to contain. For example, our mouths can hold water or food, our bowels contain waste products, and our hands can hold solids and liquids. Other hypotheses are also possible. Containment as an idea could also have sprung from animal or plant parts as models, or from inanimate structures. For example, a bowl may have its origins in a cupped hand, a broken shell, a curved leaf, or a puddle.

The idea of viewing a biological analog as a plausible origin for an invention has been studied in a recent paper by Weber, Dixon, and Llorente (1991). In that investigation, subjects were asked to rate how likely different types of hand tools developed from several different body parts/actions. Their results indicated that contemporary subjects were able to agree upon some pairings of given tools and biological metaphors (e.g., tweezers were judged to most likely have originated from a finger-to-thumb model). Other tools (e.g., brace/bit, screwdriver, and file) were rated across subjects as quite unlikely to have their origins in a biological metaphor.

The following study looks at the possibility that people perceive precursors for modern dish types in human body parts, animal parts, plant parts, and/or inanimate structures. Moreover, it attempts to assess the most plausible origins for each dish. According to Johnson's view, the most plausible origins should lie in the human body. An alternative hypothesis is that there are no differences between the plausibility ratings for the different classes of origins.

Method

Subjects. Subjects were recruited from an introductory psychology course and were given extra credit for their participation in this study. Thirty-eight subjects participated in Part A, and thirty-six subjects were involved in Part B.

Design and Procedure. In Part A of this experiment, subjects were given a pencil and paper task which presented in random order the same four dish types shown in Experiment 1 (see Appendix C). For each of the dish types, four categories of possible precursors (e.g., human body parts, animal parts, plant parts, and inanimate forms) were given in a randomized order. Thus, the four dish types and the four origin categories were all presented within-subjects. Participants were asked to write down as many instances of possible precursors as they could think of for each origin category. The initial purpose of this part of the experiment was to obtain the single best instance of each category to use as astimulus in the rating task in Part B. While such information was obtained and indeed utilized in

Part B, the frequency of responses in each origin category in Part A also seemed interesting.

In Part B of this experiment, a separate set of subjects was presented a paper and pencil task involving the same four dish types in a randomized, within-subjects format (see Appendix D). All subjects were also randomly presented with the "best instance" of each origin category for each dish type, as calculated by the frequency of a given response across subjects in Part A.

The reader may notice that the "best instances" of origin categories were not identical across dish types. For example, when given the dish type of "plate," the possible forerunners given for each category were: hands (human body parts), rock (inanimate form), <u>leaf</u> (plant part), and animal paws (animal body part). Yet when given the dish type of "drinking glass," the best instances for each category were: hands (human body parts), rock (inanimate form), <u>plant stem</u> (plant part), and animal paws (animal part). The difference in the best instances given for the plant parts makes common sense based on the shape of the dish type presented (e.g., a plant stem is more like the hollow cylinder of a drinking glass and a leaf can be flat like a plate). Therefore, the experimenter chose to sacrifice some continuity in the presentation of best instances of origin categories across dish types in order to better answer the question of how likely a category of precursors (e.g., plant parts) spurred the development of a class of inventions (e.g., dishware). Thus, the instances of each candidate origin category presented to subjects in Part B of this experiment vary slightly across the dish types.

Subjects were instructed to rate each of the possible forerunners as to how likely it came before a given dish type in the historical record. A Leikert-type scale from 1 -7 was used. A rating of "1" indicated that a possible forerunner was deemed very UNlikely to be found in the historical record of the given dish type. A rating of "7" indicated that the object presented was judged to be a very LIKELY precursor in the development of the dish type.

Results and Discussion. In Part A of this study, subjects gave more instances of the organic precursor categories (human, animal, and plant) than instances of inanimate and miscellaneous precursors. Figure 3 shows the mean frequency of responses for each dish type by origin category. Notice that the mean frequencies are higher for the organic origins (ranging from 1.0 to 1.7) than for the inanimate and miscellaneous origins (ranging from 0.5 to 0.8) across all four dish types. This could be due to the difference in availability to memory of organic versus inanimate models; that is, people can more easily recall organically based structures that are similar to a dish type in form or function than they can recall inanimate structures. Another possible explanation for this result is that subjects may have judged organic categories as more plausible precursors than inanimate categories for the dish types, so they gave more instances of the former

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Insert Figure 3 about here

A 4 x 5 (Dish x Origin) ANOVA with repeated measures on both factors was performed with Greenhouse-Geisser corrections for departure from symmetry. A significant Dish x Origin interaction effect was found, F (7.22, 267.29) = 2.33, $p < .05$. Due to this significant interaction, the main effect for Origin, F (2.68, 99.04) = 17.57, $p < .001$, is not statistically interpretable, although it is definitely interesting. It suggests that the null hypothesis that subjects would give equal numbers of precursor instances across the origin categories is not supported.

In order to compare differences in the mean frequency of response given for each of the origin categories, a Tukey's-HSD was performed. Table 7 shows the means for each cell (Dish Type/Origin Category) and indicates with an asterisk which cells were significantly different from one another at the q = .05 level. For example, in the first row the mean for the cell "Glass/Plant Origin" is significantly different from the means for the cells "Cup/Human Origin," "Bowl/Inanimate Origin," "Plate/Miscellaneous Origin," etc.

Notice that out of all of the statistically significant differences between the cell means, all but one ("Glass/Plant Origin" compared to "Cup/Human Origin") of the comparisons are between an organically based category (human, plant, or animal) and an inanimate or miscellaneous category.

Insert Table 7 about here

In Part B, a separate set of subjects rated how likely a given instance of an origin category (e.g., "a hand") was actually a precursor for each dish type. The best instances (or those responses given most frequently in Part A of this experiment) of four origin categories were presented as candidate precursors for each dish. The mean plausibility ratings for each dish type by category are shown in Figure 4. In this study, there does not appear to be as clear cut a difference between responses to the organic (human, animal, and plant) categories and the inanimate categories, as in Part A. Yet the overall plausiblity ratings for the inanimate category do appear to be slightly lower than overall ratings for the other three categories. It is unclear as to whether this indicates an actual preference to the idea that dishware most likely sprang from organic precursors or that these results merely indicate that the instances of the inanimate category were not the best possible models of that category.

Insert Figure 4 about here

In Part B of this experiment, a 4 x 4 (Dish x Origin) ANOVA with repeated measures on both factors was performed with Greenhouse-Geisser corrections for departure from symmetry. A significant Dish x Origin interaction effect was found, F (3.78, 132.42) = 15.38, p < .01. Here again, the significant interaction effect renders the significant main effect for Origin, F (2.25, 78.72) = 5.91, p < .01, uninterpretable. These results do suggest, however, that for particular dish types subjects rated certain candidate origin categories as more plausible precursors than other categories.

In order to compare the means for each origin by dish type, a Tukey's-HSD was performed. Table 8 shows which cells were significantly different from one another at the q = .05 level (as indicated by an asterisk). For example, in the first row the mean for the cell "Bowl/Animal Origin" is significantly different from the means for the cells "Plate/Inanimate Origin," "Plate/Animal Origin," "Bowl/Plant Origin," etc.

Insert Table 8 about here

In the table, carats (^) indicate the statistically significant differences between cells with inanimate origins and cells with organic origins (plant, human, or animal). Notice that most of the cells with inanimate origins show significant differences when compared to organic origin cells and that the means for the inanimate cells are lower than the means for the organic cells. For example, the mean for the cell "Plate/Inanimate Origin" (3.94) is significantly lower than the means for the cells "Bowl/Animal Origin" (5.56) and "Cup/Animal Origin" (5.50).

These results support the information found in Figure 4: there appears to be an overall difference between the subjects' plausibility ratings of the organic categories and the inanimate category, with the instances of the inanimate category ranked as less plausible precursors for the given dish types.

Experiment 3: Pathway Plausibility

Experiment 1 suggested that people perceive natural pathways for related invention states (such as different types of dishware), and Experiment 2 showed that some organic objects (such as parts of plants, animals, and human bodies) are viewed by contemporary subjects as fairly likely origins for some dish types. A question that remains unanswered is: Are some of the dish types <u>themselves</u> seen as possible precursors to other dish types, or do the results of Experiment 1 merely suggest a time sequence of invention with little meaningful connection between the separate types of dishes? In other words, did the invention of the plate spur the cognitive processes that led to the invention of the glass, or were the inventions of the plate and the glass separate cognitive phenomena originating from different sources at different times?

Based on the modal rank orderings for the four dish types--plate first, bowl second, glass third, and cup fourth --one might expect that contemporary subjects would see some ordered connections between any two of the four dishes. For example, since "Plate" was in the first position and "Glass" was in the third position in the results of Experiment 1, the assumption could be made that a plate might be a precursor in the development of a glass.

In this experiment, subjects are asked to rate (from 1 -7) the likelihood that the change in a given dish pair (e.g., "Plate to Glass") actually occurred in the historical record in the sequence shown (see Appendix E). As stated above, one possible result is that higher plausibility ratings are given to dish pairs presented in a sequence that is commensurate with the rank orderings in Experiment 1 (e.g., "Plate to Glass") and lower plausibility ratings will be given to pairs presented in a sequence that is opposite the previous rank orderings (e.g., "Glass to Plate"). An alternative outcome is that the plausibility ratings given to different dish pairs have no relation whatsoever to the perceived order of development of the two dishes comprising a pair.

In order to generalize the results of the dishware experiment, a duplicate experiment with all possible pairs of the four digging tools presented in Experiment 1 are administered to a separate set of subjects. Here, too, one possible outcome is that subjects rate tool pairs that follow the perceived sequence of development--scoop first, spade second, square shovel third, and snow shovel fourth --as more plausible than tool pairs that oppose such a sequence. For example, "Scoop to Square Shovel" might be rated a "6" or "7", indicating the subject's perception that such a change very likely occurred in the historical record; but "Square Shovel to Scoop" might be rated a "2" or "3", indicating that such a sequence is deemed fairly unlikely. Another possible outcome is that the plausibility ratings for the tool pairs are unrelated to the rank orderings from Experiment 1.

Method

Subjects. Thirty-three subjects for the dishware study and thirty-six subjects for the digging tools study were recruited from an introductory psychology course. They received extra credit for their participation in this experiment.

<u>Design and Procedure</u>. In the dishware study, the 12 pairs of dish types were presented in a randomized order in a within-subjects design (see Appendix E). Participants were asked to rate each pair as to the plausibility that dish A (e.g., a cup) actually came before dish B (e.g., a plate) in the historical record of dishware development. A Leikert-type scale from 1-7 was used. A rating of "1" indicated that the change from dish A to dish B was very UNlikely to have occurred in that sequence. For example, given the results of Experiment 1--in which the natural sequence of the four dish types was identified as plate to bowl to glass to cup--onemight expect the move from a cup to a plate to be rated as a "1". A rating of "7" indicated that the move between a given dish pair very LIKELY occurred in the order shown. Therefore, a move from a bowl to a cup might be rated a "6" or "7".

Due to the fact that the dish types were presented in all possible permutations, each of the six dish pairs was presented in two directions (e.g., "Plate to Bowl" and "Bowl to Plate"). Assuming that the subjects would rank one direction as more plausible than its opposite for each dish pair, then direction must be considered an independent factor so that the higher rankings for one direction do not cancel out the lower rankings for the opposite direction.

The digging tools study was a duplicate of the dishware study. A separate set of subjects was randomly presented with the 12 possible pairs of the digging tools and asked to rate from 1-7 how likely a given pair actually occurred in the sequence shown from tool A to tool B (see Appendix F).

Results and Discussion. Figure 5 shows the mean plausibility ratings for the dish pairs by direction. In the figure, the six dish pairs are presented in the order one would expect to be most plausible based on the results of the rank ordering in Experiment 1 (e.g., plate first, bowl second, glass third, cup fourth). These pairs are labeled as "Forward," and their reversals are labeled as "Opposite."

Insert Figure 5 about here

The hypothesis that the Forward dish pairs would be rated as most plausible appears to be supported only in the case of the "Plate to Cup" and the "Plate to Bowl" transitions. Otherwise, the Opposite dish pairs were rated as more plausible, which is contrary to the results expected from the rank ordering given in Experiment 1.

Such unexpected results could mean that while contemporary subjects do see the four dish types as having developed in a natural sequence, they do not see one dish type (e.g., plate) as being an actual precursor to the development of another dish type (e.g., glass). Rather, they may see the development of the different dish types as unrelated other than by the timing of their invention. Thus, while a plate may have come before a glass in the historical record, the invention of a plate did not spur the cognitive processes underlying the invention of a glass.

Another possible explanation for the apparent contrast between the results of this experiment and the rank orderings from Experiment 1 is that the wording in the instructions of this experiment may have been too ambiguous (see Appendix E). For instance, subjects may have understood the instructions to be asking them to rate the plausibility that dish A came directly before dish B in the historical record, that dish A actually led to the invention of dish B, or that it merely occurred at some point in time before dish B.

Although the subjects' responses to this task differed in most instances from the expected responses given the results in the rank order study, there was a significant overall agreement between the subjects' plausibility ratings of the dish pairs by direction. A significant alpha interrater reliability coefficient was obtained for Forward pairs, $\alpha = .89$, and for Backward pairs, $\alpha = .94$.

A 2 x 6 (Direction x Dish Pair) ANOVA with repeated measures on both factors was performed with Greenhouse-Geisser corrections for departure from symmetry. A significant Direction x Dish Pair interaction effect was found, F (3.84, 122.87) = 12.78, $p < .05$. A Tukey's-HSD was computed in order to compare the total mean plausibility ratings for the twelve dish pairs (see Table 9). Statistically significant differences between the mean ratings at the q = .05 level are indicated by asterisks (*). Interestingly, the idea that the mean ratings would be significantly different for the two directions of a given dish pair (Forward and Opposite) was only supported for three of the six pairs (Plate/Glass, Bowl/Cup, and Plate/Bowl).

Insert Table 9 about here

In the digging tools study, the hypothesis that subjects would rate Forward tool pairs (as based on the results of Experiment 1, with the rank ordering of scoop first, spade second, square shovel third, and snow shovel fourth) as more plausible than Opposite pairs was supported across all of the six tool pairs (see Figure 6).

It is unclear why the plausibility ratings for the digging tool pairs are more commensurate with the rank orderings from Experiment 1 than are the plausibility ratings for the dish pairs. One possible reason might be that subjects viewed the digging tools as more clearly sequenced in a specific rank order. Looking back at Tables

3 and 4, the reader will notice that the rank orderings for the digging tools in Experiment 1 were more different from one another than were the rank orderings for the dish types. Thus, it is possible that subjects in this experiment showed less ambivalence regarding the sequence of the digging tools when giving their plausibility ratings than they did regarding the sequence of the dish types.

The instructions for the dishware and the digging tools studies were exactly the same, except for the terms used for dish types and tools (see Appendixes E and F). This fact does not support the proposed explanation that the ambiguity of the instructions in the dishware study accounted for the unexpected results (specifically, that most Forward dish pairs were not rated as more plausible than their Opposites). The same instructions, when used for the digging tools study, resulted in subjects rating most Forward tool pairs as more plausible than their Opposites.

Insert Figure 6 about here

Not only did the ratings in the digging tools study seem to support the rank ordering results from Experiment 1, but the subjects in this study also highly agreed in their ratings of the tool changes. An alpha coefficient of interrater reliability was performed for each direction across the six tool pairs. Statistically significant agreement between the subjects' plausibility ratings was found for both Forward tool pairs, α = .94, and their Opposites, α = .97.

A 2 x 6 (Direction x Digging Tool) ANOVA with repeated measures on both factors was performed with Greenhouse-Geisser corrections for departure from symmetry. A significant Direction x Tool Pair interaction effect was found, F (3.38, 118.30) = 25.68, $p < .05$. In order to compare the mean plausibility ratings of the twelve total tool transitions, a Tukey's-HSD was performed. Table 10 indicates with an asterisk (*) which transitions were significantly different from one another at the q = .05 level. Notice that four of the six tool pairs were significantly different from their reversals (Scoop/Snow, Scoop/Square, Spade/Snow, and Scoop/Spade), which lends further support to the notion that contemporary subjects do view some pathways between related invention states as more plausible than others.

Insert Table 10 about here

Note also that most of the statistically significant differences between the tool transitions occurred where the Scoop placed in the last position (e.g., "Snow Shovel to Scoop" and "Square Shovel to Scoop") was compared with any other tool transition. This makes common sense given the results of Experiment 1 in which the Scoop was clearly judged to have come first. Subjects in this study appear to have agreed with that finding, because when the Scoop was presented as coming after another tool in a pair, that pair was rated as fairly implausible (also see Figure 6).

Experiment 4: Motivating Factors

The results of Experiment 1 showed that contemporary people perceive a natural sequence to the invention pathways of dishware and digging tools. This experiment searches for perceptions of possible motivating factors in taking steps along an invention path. Subjects are asked to rate the plausibility that certain food consistencies (solid/liquid) and food temperatures (hot/cold) motivated the changes between given pairs of dishes (e.g., changes from a plate to a bowl). A likely outcome is that some types of food are rated as more motivating in some dish transformations than in others. For example, hot liquids will probably be rated as a likely reason for changing from a plate to a bowl or a cup. Such a result would lend a functional explanation for the moves between dish types; the function that the dish is required to perform helps to shape the form that the dish will take. Note again that a strong historical claim is not being made. Instead, it is the subjects' perceptions that are examined.

Method

Subjects. Thirty-nine subjects from an introductory psychology course were given extra credit for thie participation in this experiment.

Design and Procedure. Subjects were given a paper and pencil task in which they were asked to rate the likelihood that the need to contain certain food types motivated the changes between a pair of different dish types (see Appendix G). All possible pairs (12 permutations) of the four dish types were presented randomly within-subjects. Participants were also presented four food types (hot liquid, hot solid, cold liquid, cold solid) in a random, within-subjects format.

The task involved rating each of the four food types as to how likely it motivated the change in dish form from A to B (e.g., from a plate to aglass). A rating of "1" indicated that the food type was a very UNlikely motivating factor in the move from dish A to dish B. For example, a "hot solid" might be rated a "1" as a very UNlikely motivator for the change from a plate to a glass. In other words, there is little need to change froma plate to a glass in order to accommodate a hot solid, such as a hot piece of meat. A rating of "7" indicated that the food type was a very LIKELY factor in the change from dish A to dish B. In moving from a plate to a glass, a cold liquid (e.g., iced tea) might be rated a "7".

Results and Discussion. For each of the twelve dish pairs, a separate 2 x 2 (Food Consistency x Food Temperature) ANOVA with repeated measures on both factors was performed. The results of the 12 ANOVAs are listed in Table 11. The reader will notice that for the dish pair "Glass to Plate" the mean ratings for the solid foods (both at 5.26) are definitely higher than those for liquids (at 1.15 and 1.18). Also, a statistically significant main effect for Food Consistency was found, F (5.4, 38) = 120.66, $p < .01$. This strongly suggests that subjects saw the need to contain a solid food, regardless of its temperature, as a likely motivating factor in changing a glass to a plate.

Insert Table 11 about here

While this result makes common sense based on the structural features of a glass and a plate (e.g., solids would be very difficult to eat from a glass), note that the claim that a glass actually came before the plate in the historical record is not being made here. Rather, it is the perception of the motivation underlying the presented transitions that is at issue here.

For "Glass to Bowl," a significant main effect for Food Temperature was found, F (3.1, 38) = 19.28, $p < .01$. The mean ratings for "Glass to Bowl" (found in Table 11) indicate that hot food, regardless of its consistency, was judged to be a more likely motivator than cold food in the move between a glass and a bowl.

Significant Temperature x Consistency interaction effects were found for the remaining dish pairs at the $p <$ .05 level (indicated in Table 11 with asterisks). Although not interpretable due to significant interactioneffects, some main effects were considered interesting and are therefore marked with a carat (^) in Table 11. For example, "Plate to Bowl" showed a suggestive main effect for Food Temperature and "Bowl to Plate" showed a suggestive main effect for Food Consistency. A Tukey's-HSD was performed for both of these transitions in order to compare the mean ratings.

Table 12 shows the results of the multiple comparisons of the mean ratings for dish pairs "Plate to Bowl" (as indicated by an asterisk) and "Bowl to Plate" (as indicated by a cross). For "Plate to Bowl, " the statistically significant differences at the $q = .05$ level were between the hot foods and the cold foods. In looking back at Table 11, notice that for "Plate to Bowl" the mean plausibility ratings were higher for hot foods than for cold foods. This suggests that subjects viewed hot food as a more likely motivator than cold food in the change from a plate to a bowl.

Insert Table 12 about here

For the reversal of that dish pair, "Bowl to Plate," Food Consistency seemed to be a more motivating factor in the transition. Table 12 shows that all of the differences between the mean ratings for the solid and liquid foods were statistically significant at the q = .05 level. The means shown for "Bowl to Plate" in Table 11 indicate that subjects judged solid food as a more likely motivating factor than liquids in the transition between the dish types.

Suggestive, though not interpretable, main effects for Food Consistency were also found for both the "Plate to Cup" and "Cup to Plate" transitions. Again, a Tukey's-HSD was used to compare the mean ratings for these dish pairs. Table 13 shows that for both "Plate to Cup" (as indicated with an asterisk) and "Cup to Plate" (indicated with a cross) the differences between all of the mean plausibility ratings for solids and liquids were statistically significant and the q = .05 level.

Insert Table 13 about here

For "Plate to Cup," the mean ratings found in Table 11 suggest that the need to contain liquids was judged to be the more likely motivating factor in the transition. For

"Cup to Plate," the mean ratings for solids were higher than for liquids, indicating that containment of solid food was a more plausible motivator in the change between the dish pair.

Experiment 5: Heuristics

The preceding experiments show that people do think of related inventions as linked in a sequential nature with common origins and that the function needed to be performed is seen as a strongly motivating factor in the development of a given invention. The next step, which is to be addressed in this experiment, is to test the subjects' knowledge of some simple rules used in moving from one dish type to another. For example, when moving from a plate to a cup with a handle, what changes must be made? The diameter is decreased, depth is added, and a handle is added. Although these changes may seem obvious to most contemporary adults, at some point in the historical record they may not have seemed so obvious. The historical database shows that plates, bowls, cups, and glasses were not all invented at the same time (Scott, 1954), so at some point in human development the idea to add or decrease diameter, depth, and/or handles was not glaringly obvious.

In this experiment, the probable outcome is that there is substantial agreement between subjects as to what heuristics were used in the steps moving from dish A to dish B. An alternative outcome, however, is thatthere is little agreement on what heuristics are involved in a given transition pair. If this _is_ the case, then the idea that a given invention can be arrived at through following heuristic rules is not supported by subjects' perceptions. However, if there is consistent agreement on the heuristics used, then it is likely that those heuristics may have been powerful ones for a given transition.

In order to generalize the observable power and usefulness of basic heuristics used in the transformation of one invention state into another, a separate set of subjects are also asked to identify what heuristic rules, if any, were used to transform one type of digging tool to another. If subjects agree on the heuristics involved in moving between a given tool pair, then the outcome would lend further power and credibility to the idea that simple "rules of thumb" may be applied to make changes among members of an invention family, whether dishware or digging tools.

Method

Subjects. All subjects were recruited from an introductory psychology course, in which they received extra credit for their participation in this experiment. Twenty -eight subjects were involved in the dishware study, and forty subjects participated in the digging tool study.

Design and Procedure. In the dishware study, subjects were given a paper and pencil task which instructed them to write down all possible steps in moving between two dish types (see Appendix H). All possible pairs (12 permutations) of the four dish types used in the preceding experiments were presented within-subjects in a random order.

The subjects' responses for each dish pair were categorized by "type of heuristic" by two separate judges. A percentage of agreement between the judges was then calculated for each heuristic across all 12 dish pairs.

The digging tools study was a duplicate of the dishware experiment in order to search for possible common heuristics used in the two different invention categories (see Appendix I). Here a separate set of subjects wasgiven the 12 possible pairs of the four digging tools used in Experiment 1 and asked to identify the changes when moving between each pair. Again, two judges categorized the heuristics for each tool pair, and a percentage of agreement between the judges was calculated for each heuristic across all tool pairs.

Results and Discussion. For the dishware study, the heuristic rules given by subjects across all of the dish pairs are shown in Table 14. The percentage of subjects reporting each rule for a given dish pair is shown. For example, for the dish pair "Plate to Bowl," 79% of the subjects reported that height was increased, 7% stated diameter increased, 54% noted diameter decreased, 7% saw a decrease in the lip or rim, and 18% gave miscellaneous heuristics. Note that not all of the rules shown in the table are applicable for each dish pair.

Insert Table 14 about here

According to the results of Table 14, the heuristic rules of increasing or decreasing height and/or diameter and adding or deleting a handle are recognizable to the majority of subjects, as suggested by relatively high percentages of subjects reporting these heuristics (when applicable for a dish pair). Some responses, included under "Enlarge" and "Condense," seemed to indicate a change in height and/or diameter, yet were not recorded under the rules "Increase/Decrease Height" or "Increase/Decrease Diameter" due to lack of specificity. For example, a response of "make it larger" might mean to increase height or diameter or both; thus, it was judged to fit under the more ambiguous classification of "Enlarge."

To establish reliability, two judges separately classified subjects' responses for each dish pair by type of heuristic. The percentage of agreement between the judges' groupings across dish pairs was at or above 75% for all heuristics, except for Delete Lip (33% agreement) and Straighten Edges (0% agreement). Those heuristics which have low percentages of agreement between the judges have low overall frequency of responses from the subjects, and a single disagreement substantially reduces reliability. These reliabilities are not as high as one likes; but given that they are based on the free-form written responses of naive subjects, they are respectable.

Table 15 shows the percentage of subjects reporting different heuristic rules in the digging tools study. Several more heuristic rules were reported overall for the digging tools as compared to the number of rules given for the dishware, possibly due to the complexity and the more ambiguous nature of the digging tool drawings. Here again, some generalresponses (e.g., "enlarge the scoop," "make it smaller," or "curve/deepen it") seemed to suggest changes in height and/or width, but were not specific enough to be included in the increase/decrease height or width categories.

Insert Table 15 about here

The percentage of agreement between the two judges' groupings of the heuristics across tool pairs was at or above 83% for all heuristics, except for Increase Blade (0% agreement), Decrease Blade (60% agreement), and Increase Height (0% agreement). The heuristic categories with low agreement between the judges all have low frequencies of responses from the subjects, and again a single disagreement drastically lowers reliability.

The percentages of subjects reporting changes in the handle and/or the shaft of the tool pairs were relatively high. Changes in the width and/or the shape of the Blade (especially making it square or curved) were also highly reported.

These results, coupled with the results of the dishware study, suggest that certain heuristic rules (such as add or delete a handle, increase or decrease width) are generalizable across different types of inventions. Some heuristics that were highly reported in one study but not in the other study (such as increase/decrease height in dishware or make changes in the shaft of the digging tools) were probably related in part to the different structures of the two invention types. This is not to say, however, that such heuristics are not generalizable to other invention types.

The heuristic rule of "increase or decrease height" in order to make changes among related inventions is often used. Consider the development of architectural structures, which have progressively become taller, resulting in the modern high-rise dwellings and skyscraper office buildings. Another variation of a living-space structure which makes use of the increase/decrease height heuristic is the camping trailer that folds down for easy transportation and pops up when in use. Of course, these are complex examples that involve much more than simple height or size changes, but they do illustrate how simple heuristics can be generalized to make changes in complex inventions.

Making changes in the shaft of related inventions other than digging tools is also seen, as in the differences between upright vacuums with a long shaft and hand-held vacuums with a short shaft. The invention pathways of other related artifacts also suggest the use of the heuristic "change the width and/or shape" of a part similar to a blade. For example, inventions which involve lenses (such as cameras, eyeglasses, contacts, microscopes, etc) often differ from one another mainly by the curve and/or diameter of the lens involved. Although this is obviously not the only heuristic used in moving between such inventions, it is certainly an important one. Also, because such heuristics give rise to infinite possible variations, other requirements such as purpose and evaluation must come into play.

Conclusion

The quasi-historical approach to the study of the perceptions of contemporary people regarding invention is certainly a useful one. By utilizing an already existing databse of artifacts, researchers may continue to gain an understanding of how modern people view related inventions. Such contemporary viewpoints may or may not differ from the actual historical record of inventions. More importantly, present-day subjects' responses to invention studies open a window into the thought processes that may be used to change and improve upon inventions. From this information, psychologists gain a conceptual organization of the inventive process.

The strong agreement between subjects' perceptions in the preceding experiments is so compelling that it sheds light on the way humans think about the creative process. These results suggest the following concepts about human perceptions regarding the process of invention:

1) People think of some related inventions as linked in sequential time-lines, or natural pathways. A common way of viewing such pathways is that they progress from simple artifacts to inventions of increasing complexity.

2) Contemporary people see organic origins (such as parts of plants, animals, or human bodies) as more plausible than inanimate origins (such as rock formations) for some simple, early inventions. Subjects may also view a simple invention (such as a scoop) as an actual precursor in the development of a later, more complex invention (such as a spade).

3) The function that a new artifact is to serve is seen as a motivating factor behind its invention. For example, subjects viewed the need to contain liquids as having spurred the development of particular dish types, such as a bowl and a glass.

4) In the change between two related inventions, some heuristics, or "rules of thumb," are readily recognizable. These heuristcs, such as "increase the height" of a given artifact in order to make a new one, may be generalizable to other classes of inventions. In this study, similar heuristics were reported for the changes between different types of dishware and for different digging tools.

Possible future steps in the study of perceptions of the process of invention may include: 1) Research into the life-span development of the psychological processes underlying invention, involving comparative studies with children, adolescents, and adults as subject groups, and 2) studies involving subject populations from different cultures and genders, to note similarities and variations in thinking about inventions and heuristics.

The study of the inventive process not only allows psychologists to research probelm-solving and creativity in a more concrete, applicable way than usually undertaken, it also places the cognitive sciences in a uniquely important interactive relationship with the world of technology. Psychologists can make use of the products of technology to learn more about the cognitive processes that underlie inventions. As our knowledge base regarding inventiveness grows, psychologists might then provide information to the public that may aid in the invention of new products. Such information could possibly result in: 1) a larger number of people inventing new artifiacts, 2) higher efficiency and more rapid progress inthe development of inventions, and/or 3) higher overall quality and quantity of inventions. Thus, the field of cognitive psychology, together with technology and business, would be an important information source for people interested in producing inventive ideas.

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Appendix A

Experiment 1 (Dishware)

Shown below are four types of dishware. On the line below each picture, indicate by numbering 1 through 4 which dish type was invented first, second, third, and fourth. Give a brief explanation for your ranking below.

Why did you think your number 1 was invented first?

Why did you think your number 2 was invented second?

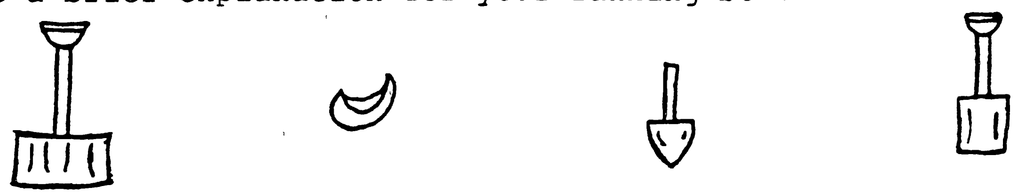
Why did you think your number 3 was invented third?

Why did you think your number 4 was invented fourth?

Appendix B

Experiment 1 (Digging Tools)

Shown below are four types of digging tools. On the line below each picture, indicate by numbering 1 through 4 which digging tool was invented first, second, third, and fourth. Give a brief explanation for your ranking below.



__________ __________ __________ __________

Why did you think your number 1 was invented first?

Why did you think your number 2 was invented second?

Why did you think your number 3 was invented third?

Why did you think your number 4 was invented fourth?

Appendix C

Experiment 2 (Part A)

Four different types of dishes are shown below. Underneath each dish type are four categories of things that may have come before each dish in its development (A,B,C, and D). For each dish type, write down as many instances as you can of things in each category that may have been forerunners in the development of that dish.

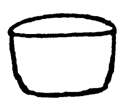
I. 

A. Animal Parts

B. Inanimate Forms

C. Plant Parts

D. Human Body Parts

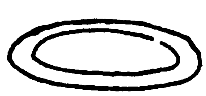
II. 

A. Human Body Parts

B. Plant Parts

C. Animal Parts

D. Inanimate Forms

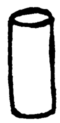
III. 

A. Plant Parts

B. Inanimate Forms

C. Human Body Parts

D. Animal Parts

IV. 

A. Inanimate Forms

B. Plant Parts

C. Human Body Parts

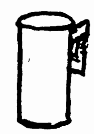
D. Animal Parts

Appendix D

Experiment 2 (Part B)

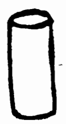
Four different types of dishes are shown on the left-hand side of the next page. To the right of each dish type, four things are listed which may or may not have come before in the development of each dish (e.g., rock, leaf, etc.). Your task is to rate each possible forerunner as to how likely it is that it came before the given dish type in the historical record. A rating of "1" means that the thing was very UNlikely to be found in the historical record of the given dish type. A rating of "7" means that the thing was very LIKELY a forerunner in the development of the dish type. If a thing is somewhere between very UNlikely at all and very LIKELY, then you would fill in a middle range number between "1" and "7".

For example, for the following dish type:



you might rate a flat rock as a "1" or "2" to indicate that it was very UNlikely a forerunner in the dish type's development. However, a hollow tree trunk might be rated as a "5" or "6" to indicate that it was LIKELY a forerunner for this dish type.

Remember, the rating scale: "1" is very UNlikley
"7" is very LIKELY

DISH TYPE	POSSIBLE FORERUNNER	RATING
1. 	a. hands	_____
	b. rock	_____
	c. leaf	_____
	d. animal paws	_____
2. 	a. rock	_____
	b. animal paws	_____
	c. hands	_____
	d. plant stem	_____
3. 	a. hands	_____
	b. rock	_____
	c. shell	_____
	d. leaf	_____
4. 	a. shell	_____
	b. leaf	_____
	c. hands	_____
	d. rock	_____

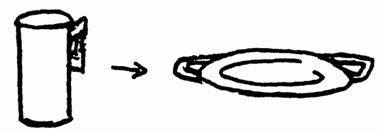
Appendix E

Experiment 3 (Dishware)

Listed on page 2 are possible changes from one type of dishware to another, such as changing Dish A to Dish B in the example at the top of the table. These changes may or may not have actually occurred in the development of different types of dishware.

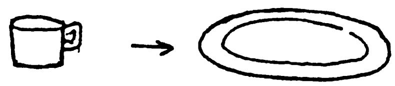
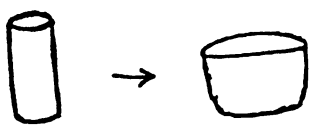
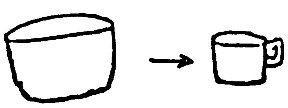
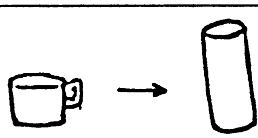
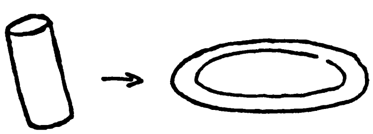
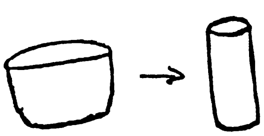
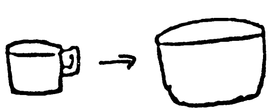
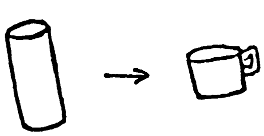
In the space to the right of each possible change, please rate how likely it is that this change actually occurred in this sequence in the historical record of dishware development. A rating of "1" means that the change is very UNlikely to be found in the historical record. A rating of "7" means that the change very LIKELY occurred in history in the sequence shown. If a change between dish types is somewhere between very UNlikely at all and very LIKELY, then you would fill in a middle range number between "1" and "7".

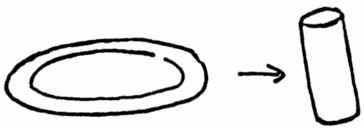
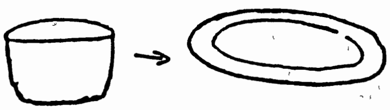
For example, in moving from Dish A to Dish B:



you might rate this change as a "1" or a "2" to indicate that Dish B was very UNlikely to follow the development of Dish A in history.

Remember, the rating scale: "1" is very UNlikely
"7" is very LIKELY

Dish Changes A.	B.	Rating (1=very UNlikely, 7=very LIKELY)
		
		
		
		
		
		
		
		
		

Dish Change A.	B.	Rating (1=very UNlikely, 7=very LIKELY)
		
		
		

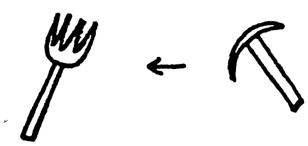
Appendix F

Experiment 3 (Digging Tools)

Listed on page 2 are possible changes from one type of digging tool to another, such as changing Tool A to Tool B in the example at the top of the table. These changes may or may not have actually occurred in the development of different types of digging tools.

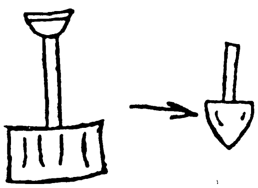
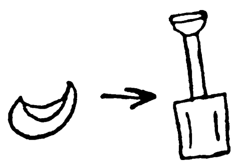
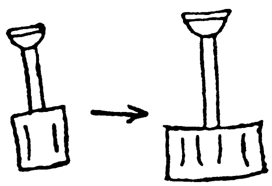
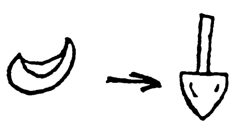
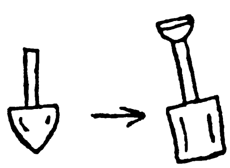
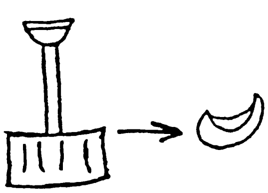
In the space to the right of each possible change, please rate how likely it is that this change actually occurred in this sequence in the historical record of digging tool development. A rating of "1" means that the change is very UNlikely to be found in the historical record. A rating of "7" means that the change very LIKELY occurred in history in the sequence shown. If a change between tool types is somewhere between very UNlikely at all and very LIKELY, then you would fill in a middle range number between "1" and "7".

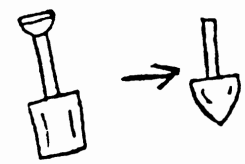
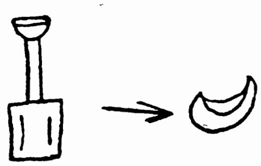
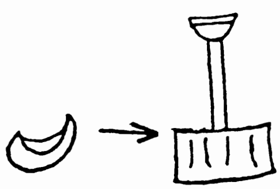
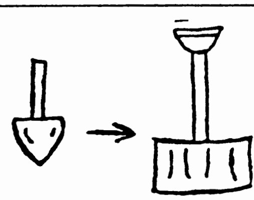
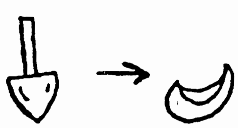
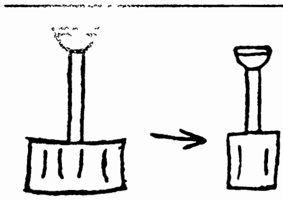
For example, in moving from Tool A to Tool B:



you might rate this change as a "4" or a "5" to indicate that Tool B was moderately likely to follow the development of Tool A in history.

Remember, the rating scale: "1" is very UNlikely
"7" is very LIKELY

Tool Change A. B.	Rating (1=very UNlikely, 7=very LIKELY)
	
	
	
	
	
	

Tool Change A. B.	Rating (1=very UNlikely, 7=very LIKELY)
	
	
	
	
	
	

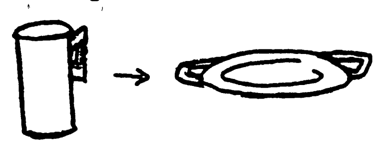
Appendix G

Experiment 4

On the left side of the table on page 2 are possible dish changes from one type of dishware to another, such as changing Dish A to Dish B in the example at the top of the table. These changes may or may not have actually occurred in the development of different types of dishware.

On the right side of the table are four different types of food: **hot/liquid** (such as coffee), **cold solid** (such as a cold piece of meat), **hot/solid** (such as a steamed vegetable), and **cold/liquid** (such as an iced beverage). Please rate for each possible dish change how likely it is that each type of food motivated the change from the first dish in the pair to the second. A rating of "1" means that the food type was a very UNlikely motivating factor in the change from the first dish type to the second. A rating of "7" means that the food type was very LIKELY a motivating factor in the change. If a food type is somewhere between very UNlikely at all and very LIKELY, then you would fill in a middle range number between "1" and "7".

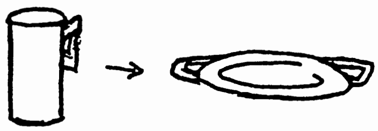
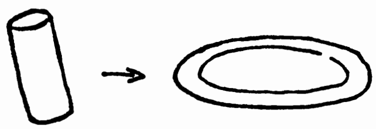
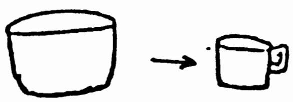
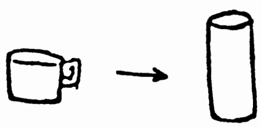
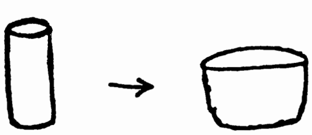
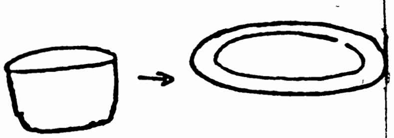
In the example figure at the top of the table, the change is from Dish A to Dish B:



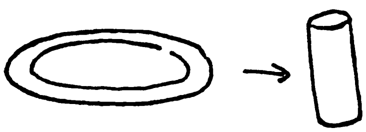
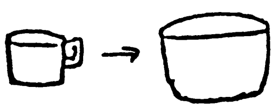
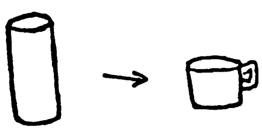
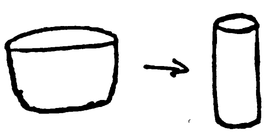
As noted in the table, you might give a rating of "1" to indicate that it is very UNlikely that a cold/liquid motivated the change from Dish A to Dish B. However, you might give a very high rating, a "6" or "7", for the cold/solid food type.

Remember, the rating scale: "1" is very UNlikely
"7" is very LIKELY

Food Type

Dish Change A---------->B	Hot/ Liquid (like coffee)	Cold/ Solid (like cold meat)	Hot/ Liquid (like steamed vegetable)	Cold/ Liquid (like iced beverage)
				
				
				
				
				
				
				
				

Food Type

Dish Change A---------->B	Hot/ Liquid (like coffee)	Cold/ Solid (like cold meat)	Hot/ Liquid (like steamed vegetable)	Cold/ Liquid (like iced beverage)
		—		
				
				
				
				

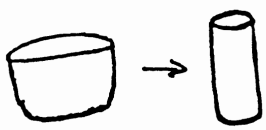
Appendix H

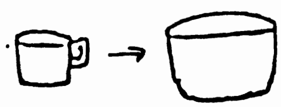
Experiment 5 (Dishware)

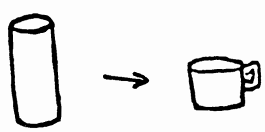
On the left side of the page below are possible changes from one type of dishware to another, such as the change from Dish A to Dish B. These changes may or may not have actually occurred in the development of different types of dishware.

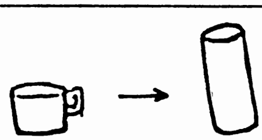
You are an inventor who wants to change Dish A to Dish B. In the space to the right of each pair of dish types, write down as many steps as you can think of in order to move from Dish A to Dish B.

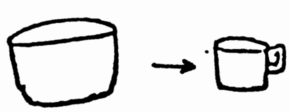
Dish Change
A. B.



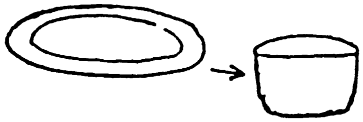
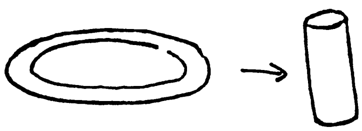
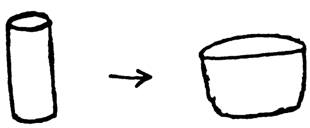
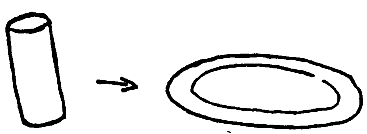
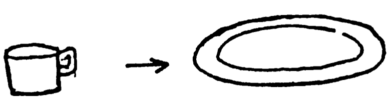








Dish Change

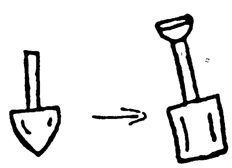
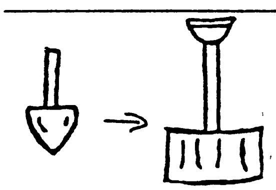
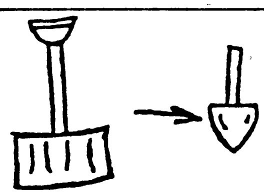
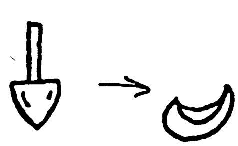
A.	B.
	
	
	
	
	
	

Appendix I

<u>Experiment 5 (Digging Tools)</u>

On the left side of the page below are possible changes from one type of digging tool to another, such as the change from Tool A to Tool B. These changes may or may not have actually occurred in the development of different types of digging tools.

You are an inventor who wants to change Tool A to Tool B. In the space to the right of each pair of tools, write down as many steps as you can think of in order to move from Tool A to Tool B.

Tool Change A. B.	
	
	
	
	
	

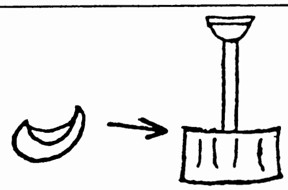
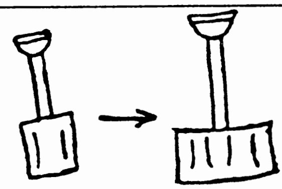
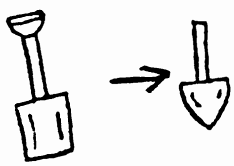
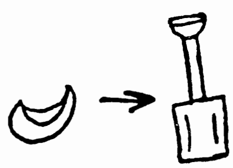
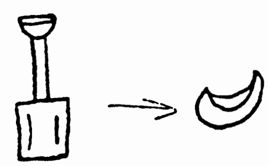
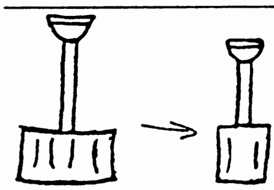
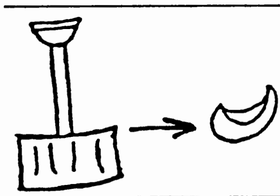
Tool Change	
A.	B. — —
	
	
	
	
	
	
	

Table 1

Frame Structure for a Cup with a Handle

Slot names have the initial letter capitalized and they are italicized; values are in lowercase.

Superordinate category: container; dishware.

General purpose/function: to hold liquids; to keep hands from getting burned or messy; manners in drinking.

Physical principles: containment; lever action with handle to add ease in pouring; safety in physically separating hot surface from hand.

Specializations: measuring cup.

Related inventions: bowl; drinking glass; pitcher.

Need: high, to contain liquids; for sanitation; to avoid messiness; to avoid burning hands.

Global evaluation: effective for drinking requirements.

(table continues)

Table 1 (Continued)

Parts Analysis (slots along the top of the table and values in the body)

Part	Material	Evaluation
"cup"	ceramic, metal, glass	good for liquids; not as effective for some solid foods (difficult to reach food with a knife)
handle	ceramic, metal, glass	effective for prevention of burning, but can break off

Precursor inventions: cupped hand, half shell, animal stomach (?)

Successor inventions: disposable plastic cups; cups with lids for no-spill traveling

Table 2

Frame Structure of a Theoretical Restaurant Script (Adapted from Schank & Abelson, 1977)

Slot names have the initial letter capitalized and they are italicized; values are in lowercase.

Name:	restaurant	*Props*:	tables
Roles:	customer		menu
	waiter		food
	cook		bill
	cashier		money
	owner		tip
Entry conditions:	customer hungry		
	customer has money		
Results:	customer has less money		
	owner has more money		
	customer is not hungry		

(table continues)

Table 2 (Continued)

Frame Structure of a Theoretical Restaurant Script

Scene 1 - Entering:	customer enters restaurant
	customer looks for table
	customer decides where to sit
	customer goes to table
	customer sits down
Scene 2 - Ordering:	customer picks up menu
	customer looks at menu
	customer decides on food
	customer signals waitress
	waitress comes to table
	customer orders food
	waitress goes to cook
	waitress gives food order to cook
	cook prepares food
Scene 3 - Eating:	cook gives food to waitress
	waitress brings food to customer
	customer eats food
Scene 4 - Exiting:	waitress writes bill
	waitress goes over to customer
	waitress gives bill to customer
	customer gives tip to waitress
	customer goes to cashier
	customer gives money to cashier
	customer leaves restaurant

Table 3: Experiment 1

<u>Frequency of Rank Order (Dishware)</u>

Dish Type	First	Second	Third	Fourth
Plate	20	5	9	2
Bowl	12	21	2	1
Glass	4	7	21	4
Cup	0	3	4	29

N = 36 Subjects.

Table 4: Experiment 1

Frequency of Rank Order (Digging Tools)

Tool Type	First	Second	Third	Fourth
Scoop	35	1	1	1
Spade	1	34	1	2
Square	1	2	31	4
Snow	1	1	5	31

N = 38 Subjects.

Table 5: Experiment 1

Frequency of First Type of Reason Given for Rank Order #1 (Dishware)

Type of Reason	Observed	*Expected	*Residual
Simplest	16	5.14	10.86
Specific Use	7	5.14	1.86
Flattest	5	5.14	- .14
Most Natural	3	5.14	- 2.14
Most Universal	3	5.14	- 2.14
Most Portable	1	5.14	- 4.14
Miscellaneous	1	5.14	- 4.14

N = 36 Subjects.

*Note: Expected frequency is based on the chi-square assumption that frequencies will be the same across all types of reasons. Residual refers to the differences between observed and expected frequencies.

Table 6: Experiment 1

<u>Frequency of First Type of Reason Given for Rank Order #1 (Digging Tools)</u>

Type of Reason	Observed	*Expected	*Residual
Most Primitive	14	7.60	6.40
Simplest	13	7.60	5.40
Most Natural	5	7.60	-2.60
Miscellaneous	4	7.60	-3.60
Specific Use	2	7.60	-5.60

N = 38 Subjects.

*Note: Expected frequency is based on the chi-square assumption that frequencies will be the same across all types of reasons. Residual refers to the differences between observed and expected frequencies.

Table 7: Experiment 2, Part A

Tukey's Multiple Comparisons of Mean Frequency of Response for Possible Origins

Dish/Origin	Dish/Origin Means																			
	Glass Plant	Plate Human	Bowl Anim	Glass Human	Plate Plant	Cup Plant	Cup Anim	Plate Anim	Bowl Plant	Glass Anim	Bowl Human	Cup Human	Bowl Inan	Plate Misc	Plate Inan	Glass Misc	Cup Inan	Cup Misc	Bowl Misc	Glass Inan
	1.71	1.66	1.61	1.47	1.45	1.40	1.37	1.37	1.32	1.29	1.29	1.13	0.82	0.79	0.76	0.63	0.63	0.58	0.58	0.45
Glass/Plant												*	*	*	*	*	*	*	*	*
Plate/Human													*	*	*	*	*	*	*	*
Bowl/Anim													*	*	*	*	*	*	*	*
Glass/Human													*	*	*	*	*	*	*	*
Plate/Plant													*	*	*	*	*	*	*	*
Cup/Plant													*	*	*	*	*	*	*	*
Cup/Animal													*	*	*	*	*	*	*	*
Plate/Anim													*	*	*	*	*	*	*	*
Bowl/Plant															*	*	*	*	*	*
Glass/Anim																*	*	*	*	*
Bowl/Human																*	*	*	*	*
Cup/Human																		*	*	*
Bowl/Inan																				
Plate/Misc																				
Plate/Inan																				
Glass/Misc																				
Cup/Inan																				
Cup/Misc																				
Bowl/Misc																				
Glass/Inan																				

N = 38 Subjects

* = statistically significant difference; q = .05 for all tests

Table 8: Experiment 2, Part B

Tukey's Multiple Comparisons of Mean Plausibility Ratings (1-7) for Possible Origins

Dish/Origin	Dish/Origin Means															
	Bowl Anim	Cup Anim	Cup Human	Plate Human	Bowl Human	Glass Plant	Glass Human	Plate Plant	Plate Inan	Plate Anim	Bowl Plant	Cup Plant	Bowl Inan	Glass Anim	Cup Inan	Glass Inan
	5.56	5.50	5.25	5.03	4.86	4.64	4.47	4.47	3.94	2.94	2.94	2.78	2.64	2.50	2.44	2.42
Bowl/Animal									*^	*	*	*	*^	*	*^	*^
Cup/Animal									*^	*	*	*	*^	*	*^	*^
Cup/Human										*	*	*	*^	*	*^	*^
Plate/Human										*	*	*	*^	*	*^	*^
Bowl/Human										*	*	*	*^	*	*^	*^
Glass/Plant										*	*	*	*^	*	*^	*^
Glass/Human										*	*	*	*^	*	*^	*^
Plate/Plant										*	*	*	*^	*	*^	*^
Plate/Inan															*	*
Plate/Animal																
Bowl/Plant																
Cup/Plant																
Bowl/Inan																
Glass/Animal																
Cup/Inan																
Glass/Inan																

N = 36 Subjects

* = statistically significant difference; q = .05 for all tests

^ = statistically significant difference between organic (human, animal, or plant) and inanimate origins

Table 9: Experiment 3 (Dishware)

Tukey's Multiple Comparisons of Mean Plausibility Ratings (1-7) for Dish Pairs

Dish Pairs	Dish Pairs Means											
	Cup-Plate	Plate-Glass	Bowl-Cup	Plate-Cup	Bowl-Glass	Glass-Plate	Glass-Cup	Bowl-Plate	Glass-Bowl	Cup-Glass	Cup-Bowl	Plate-Bowl
	1.94	2.21	2.24	2.67	3.64	3.73	4.03	4.03	4.21	4.85	4.85	5.58
Cup-Plate					*	*	*	*	*	*	*	*
Plate-Glass					*	*^	*	*	*	*	*	*
Bowl-Cup						*	*	*	*	*	*^	*
Plate-Cup									*	*	*	*
Bowl-Glass												*
Glass-Plate												*
Glass-Cup												*
Bowl-Plate												*^
Glass-Bowl												
Cup-Glass												
Cup-Bowl												
Plate-Bowl												

N = 33 Subjects

* = statistically significant difference; q = .05 for all tests

^ = significant difference between the two directions of a dish pair

Table 10: Experiment 3 (Digging Tools)

Tukey's Multiple Comparisons of Mean Plausibility Ratings (1-7) for Digging Tool Pairs

Tool Pairs	Tool Pairs Means											
	Snow-Scoop	Square-Scoop	Spade-Scoop	Snow-Spade	Scoop-Snow	Square-Spade	Snow-Square	Scoop-Square	Spade-Snow	Spade-Square	Scoop-Spade	Square-Snow
	1.42	1.53	2.00	3.22	4.00	4.39	4.44	4.47	4.61	4.75	4.89	5.81
Snow-Scoop				*	*^	*	*	*	*	*	*	*
Square-Scoop				*	*	*	*	*^	*	*	*	*
Spade-Scoop					*	*	*	*	*	*	*	*
Snow-Spade									*^	*	*^	*
Scoop-Snow												*
Square-Spade												*
Snow-Square												
Scoop-Square												
Spade-Snow												
Spade-Square												
Scoop-Spade												
Square-Snow												

N = 36 Subjects

* = statistically significant difference; q = .05 for all tests

^ = significant difference between the two directions of a tool pair

Table 11: Experiment 4

2 x 2 (Food Consistency x Food Temperature) ANOVAs for 12 Dish Pairs

Dish Pair	Means for Consistency/Temperature Combinations				Consistency		Temperature		Consistency x Temperature	
	Hot/Liquid	Hot/Solid	Cold/Liquid	Cold/Solid	F	p	F	p	F	p
Glass-Plate	1.15	5.26	1.18	5.26	120.66~	.01	.01	.93	.01	.91
Glass-Bowl	3.51	4.31	2.33	3.03	2.78	.10	19.28~	.01	.06	.81
Plate-Bowl	3.64	4.28	3.13	2.85	.13	.72	19.69^	.01	6.42*	.02
Bowl-Plate	1.56	4.92	1.26	5.51	117.54^	.01	.69	.41	7.98*	.01
Plate-Cup	5.46	1.92	4.31	1.87	30.92^	.01	6.52	.15	11.01*	.01
Cup-Plate	1.41	5.18	1.10	5.62	149.08^	.01	.23	.63	4.47*	.04
Cup-Glass	3.15	1.39	5.72	1.15	119.21	.01	34.38	.01	33.42*	.01
Glass-Cup	5.95	2.00	3.18	1.46	58.70	.01	46.02	.01	22.15*	.01
Bowl-Cup	5.80	1.69	3.64	1.41	62.79	.01	59.58	.01	24.22*	.01
Cup-Bowl	2.90	4.49	2.49	2.80	4.14	.05	21.30	.01	6.84*	.01
Bowl-Glass	4.05	1.21	5.90	1.21	226.58	.01	27.59	.01	24.39*	.01
Plate-Glass	3.87	1.62	5.97	1.23	84.05	.01	31.27	.01	40.61*	.01

N = 39 Subjects

* = Consistency x Temperature interaction effects significant at $p<.05$ level

~ = interpretable significant main effects at $p<.05$ level

^ = interesting significant main effects that are not interpretable due to significant interaction effects

Table 12: Experiment 4

Tukey's-HSD Multiple Comparisons of Mean Plausibility Ratings (1-7) for Food Temperature & Consistency: Plate to Bowl vs. Bowl to Plate

	Cold Solid	Hot Solid	Hot Liquid	Cold Liquid
Cold Solid		*	*+	+
Hot Solid			+	*+
Hot Liquid				
Cold Liquid				

N = 39 subjects; q = .05 for all tests

* = statistically significant difference for "Plate to Bowl"

+ = statistically significant difference for "Bowl to Plate"

Table 13: Experiment 4

Tukey's-HSD Multiple Comparisons of Mean Plausibility Ratings (1-7) for Food Temperature & Consistency: Plate to Cup vs. Cup to Plate

	Cold Solid	Hot Solid	Hot Liquid	Cold Liquid
Cold Solid			*+	*+
Hot Solid		*	*+	*+
Hot Liquid				
Cold Liquid				

N = 39 subjects; q = .05 for all tests

* = statistically significant difference for "Plate to Cup"

+ = statistically significant difference for "Cup to Plate"

Table 14: Experiment 5 (Dishware)

Percentage of Subjects Reporting Heuristic Rules for Each Dish Pair

Dish Pair	Heuristic Rules												
	add height	minus height	add diameter	minus diameter	add handle	minus handle	add lip	minus lip	enlarge (general)	condense (general)	straighten edges	make rounder	misc.
Plate-Bowl	79	-	7	54	-	-	-	7	-	-	-	-	18
Plate-Cup	86	-	-	75	82	-	-	-	-	-	-	-	14
Plate-Glass	86	-	-	75	-	-	-	4	-	-	-	-	14
Bowl-Plate	-	100	71	-	-	-	18	-	-	-	-	-	-
Bowl-Cup	-	29	-	32	82	-	-	-	-	54	4	-	7
Bowl-Glass	89	-	-	82	-	-	-	-	-	-	4	-	7
Cup-Plate	-	96	75	-	-	57	18	-	-	-	-	-	11
Cup-Bowl	18	-	71	-	-	71	-	-	61	-	-	4	7
Cup-Glass	86	-	4	21	-	82	-	-	-	-	-	-	-
Glass-Plate	-	93	75	-	-	-	18	-	-	-	-	-	7
Glass-Bowl	-	79	96	-	-	-	-	-	-	-	-	11	4
Glass-Cup	-	100	18	-	96	-	-	-	-	-	-	-	-

N = 28 subjects

NOTE: Subjects were asked to report as many heuristic rules as possible, so percentages across rules for each dish pair will not add to 100. Percentages were rounded up to the nearest whole number.

Table 15: Experiment 5 (Digging Tools)

Percentage of Subjects Reporting Heuristic Rules for Each Digging Tool Pair

Tool Pair	Heuristic Rules														
	+ ht	- ht	+ diam	- diam	+ handle	- handle	+ shaft	- shaft	enlarge scoop	condense scoop	square edges	curve scoop	sharpen point	flatten scoop	misc.
Sccoop-Spade	-	-	-	-	-	-	100	-	3	3	-	-	30	60	55
Scoop-Square	-	-	-	-	95	-	68	-	20	-	50	-	-	58	18
Scoop-Snow	-	-	30	-	98	-	70	-	25	-	35	-	-	60	13
Spade-Scoop	-	-	-	-	-	-	-	95	-	13	-	70	8	-	38
Spade-Square	-	-	10	-	98	-	13	-	8	-	70	-	3	8	10
Spade-Snow	3	-	-	63	90	-	35	-	20	-	60	-	-	-	15
Square-Scoop	-	-	-	23	-	93	-	55	-	8	-	65	13	-	30
Square-Spade	-	-	-	-	-	93	-	13	-	3	-	-	80	-	28
Square-Snow	-	8	73	-	18	-	33	-	20	-	-	-	-	-	10
Snow-Scoop	-	-	-	45	-	95	-	58	-	8	-	73	13	-	30
Snow-Spade	-	-	-	-	40	90	-	35	-	10	-	-	78	-	23
Snow-Square	3	-	-	63	-	38	-	30	-	38	-	-	3	-	-

N = 40 subjects

NOTE: Subjects were asked to report as many heuristic rules as possible, so percentages across rules for each tool pair will not add to 100. Percentages were rounded up to the nearest whole number.

Figure Caption

Figure 1. Necessary transformations between a plate and a bowl (+ indicates the presence of a characteristic, - indicates the absence of a characteristic).

Feature Present	Plate	Bowl
diameter	+	+
depth	–	+
handle	–	–

Figure Caption

Figure 2. Possible transformations between a square shovel and a snow shovel (* indicates the presence of a characteristic, + indicates an increase in the characteristic, o indicates no change in the characteristic).

Feature	Square Shovel	Snow Shovel
scoop width	*	+
scoop height	*	o
shaft length	*	+
handle width	*	+

Figùre Caption

Figure 3. Experiment 2, Part A: Mean frequency of response for each dish type by origin category (N = 38 subjects).

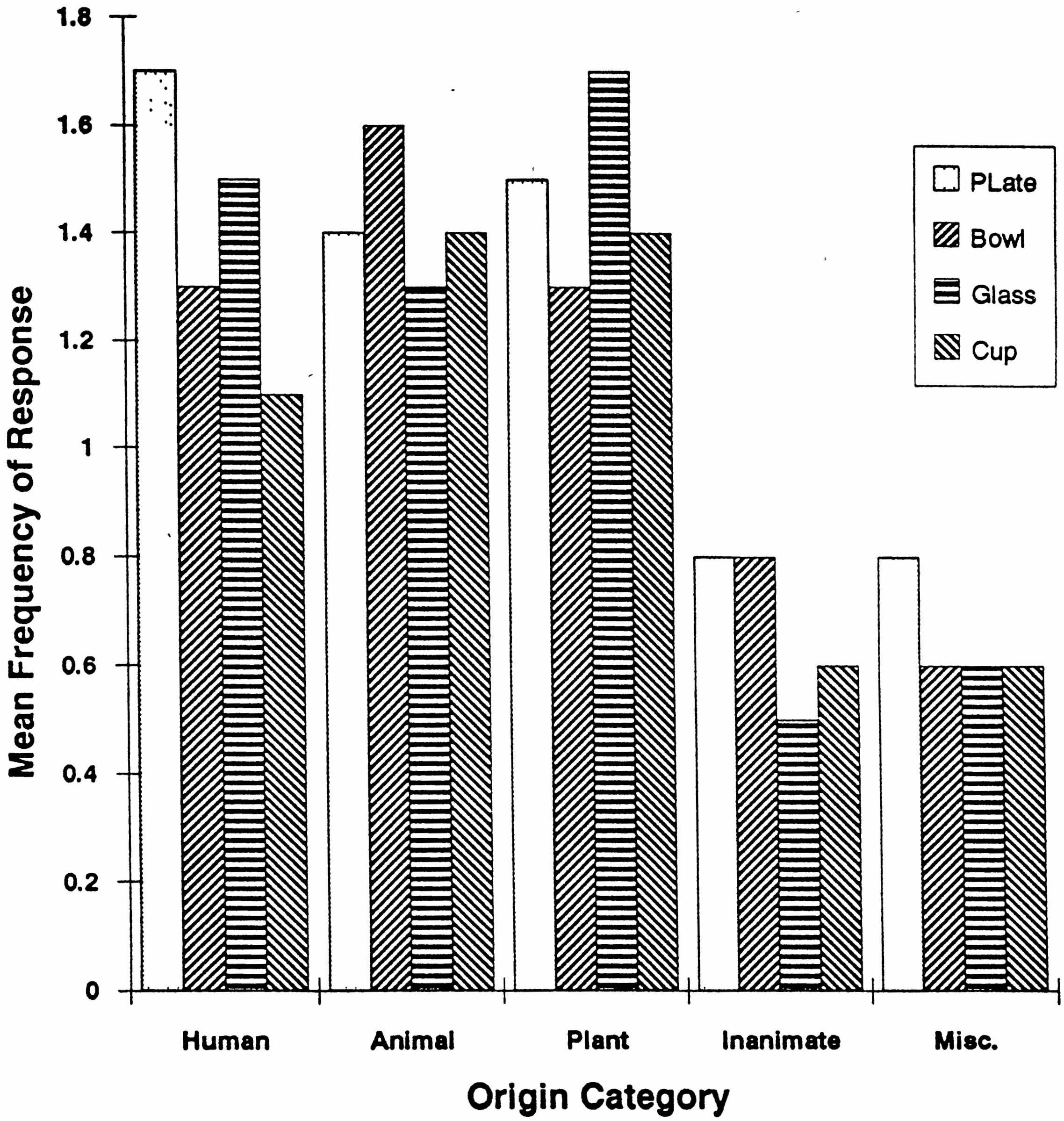

1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Mean Frequency of Response
PLate
Bowl
Glass
Cup
Human
Animal
Plant
Inanimate
Misc.
Origin Category

Figure Caption

Figure 4. Experiment 2, Part *B*: Mean plausibility ratings (1-7) for dish types by origin category (N = 36 subjects).

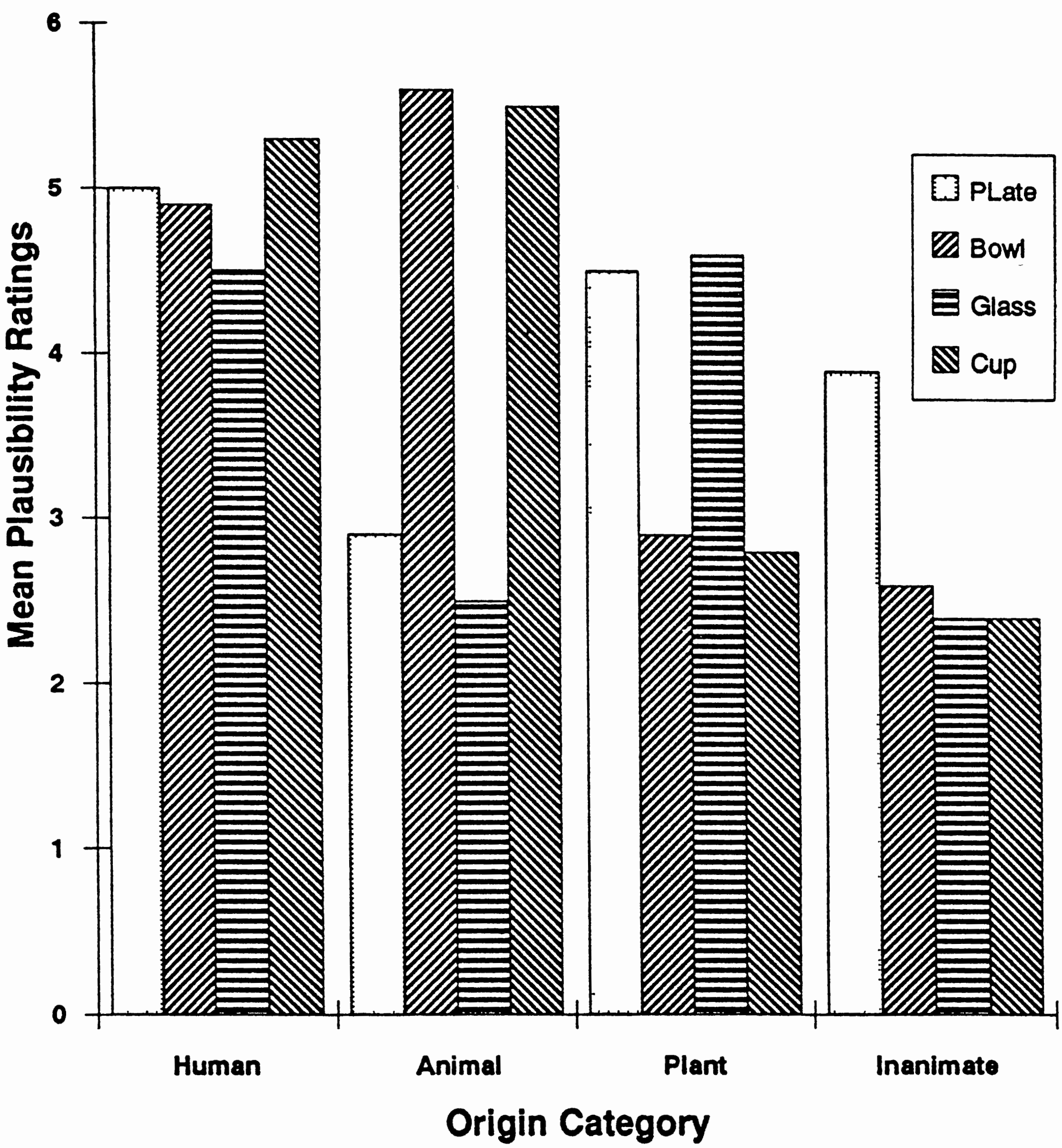
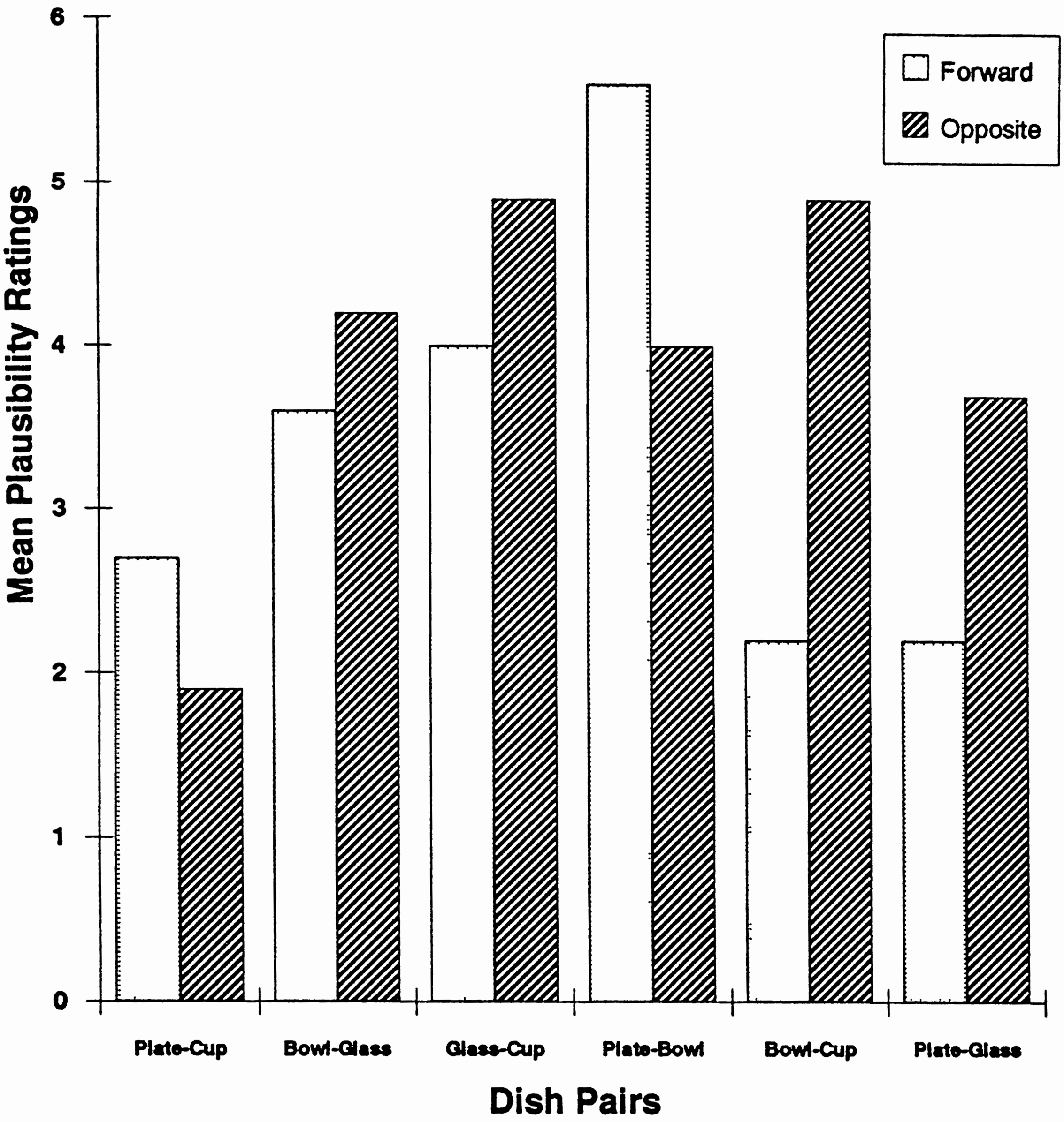

Mean Plausibility Ratings
6
5
4
3
2
1
0
PLate
Bowl
Glass
Cup
Human
Animal
Plant
Inanimate
Origin Category

Figure Caption

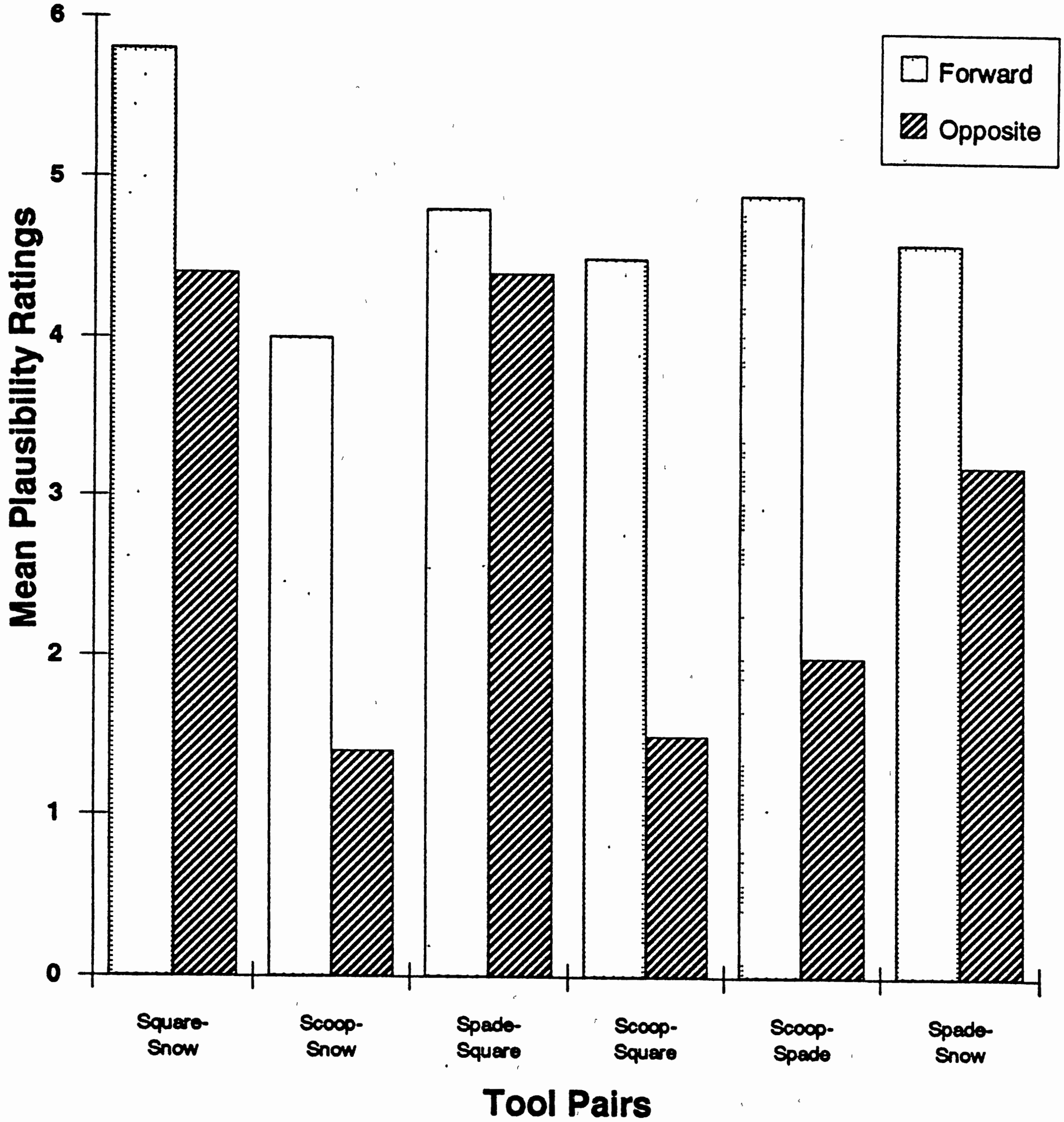
Figure 5. Experiment 3 (Dishware): Mean plausibility ratings (1-7) for dish pairs by direction ("Forward" pairs are derived from the rank orderings from Experiment 1, with plate first, bowl second, glass third, and cup fourth. "Opposite" pairs are the reversals of forward pairs. _N_ = 33 subjects).



Mean Plausibility Ratings
0
1
2
3
4
5
6
Forward
Opposite
Plate-Cup
Bowl-Glass
Glass-Cup
Plate-Bowl
Bowl-Cup
Plate-Glass
Dish Pairs

Figure Caption

Figure 6. Experiment 3 (Digging Tools): Mean plausibility ratings (1-7) for tool pairs by direction ("Forward" pairs are derived from the rank orderings from Experiment 1, with scoop first, spade second, square shovel third, and snow shovel fourth. "Opposite" pairs are the reversals of forward pairs. N = 36 subjects).



Mean Plausibility Ratings
6
5
4
3
2
1
0
Forward
Opposite
Square-
Snow
Scoop-
Snow
Spade-
Square
Scoop-
Square
Scoop-
Spade
Spade-
Snow
Tool Pairs

VITA

Stacey L. Dixon

Candidate for the Degree of

Doctor of Philosophy

Thesis: NATURAL PATHWAYS IN THE PERCEPTION OF INVENTION SEQUENCE

Major Field: Clinical Psychology

Biographical:

Personal Data: Born in Tulsa, Oklahoma, January 26, 1964, daughter of Jim and Marilyn Dixon; married to Rob Crockett, August 11, 1987.

Education: Graduated from Nathan Hale High School, Tulsa, Oklahoma, in 1982; received Bachelor of Science Degree in Psychology with a Minor in Early Childhood Development from Oklahoma State University in 1986; received Master of Science Degree in Psychology from Oklahoma State University in 1988; completed requirements for the Doctor of Philosophy Degree at Oklahoma State University in 1992; completed predoctoral internship in psychology at the University of Tennessee Consortium Internship in Professional Psychology in Memphis, Tennessee, in 1991; currently receiving postdoctoral fellowship in psychology at the University of Tennesse Boling Center for Developmental Disabilities (1991-1992).

Professional Experience: Research Assistant, Department of Psychology, Oklahoma State University, August, 1986, to August, 1987; Course Grader, Correspondence Studies, Oklahoma State University, September, 1986 to September, 1987; Study Skills Instructor, College of Veterinary Medicine, Oklahoma State University, September, 1987, to December, 1987; Psychological Associate, Psychological Services Center, Oklahoma State University, September, 1987, to May, 1990; Graduate Instructor of Introductory Psychology, Oklahoma State Univeristy, August, 1987, to May, 1988; Consultant/Designer of Play Therapy Room, Psychological Services Center, Oklahoma State University, June, 1988, to May, 1990; Assistant Coordinator of The Inventing Mind Conference in Tulsa, Oklahoma, June, 1988, to August, 1988; Family Therapist, Marriage & Family Clinic, Oklahoma State University, September, 1988, to August, 1989; Psychological Intern, Payne County Guidance Center, Stillwater, Oklahoma, September, 1988, to June, 1989; Psychological Assistant, Payne County Guidance Center, Stillwater, Oklahoma, September, 1989, to June 1990; Predoctoral Intern, University of Tennesse, Memphis, Tennessee, September, 1990, to August, 1991; Postdoctoral Fellow, University of Tennessee Boling Center for Developmental Disabilities, September, 1991, to present.

Licensure: Psychological Examiner, State of Tennessee, #PE-001733, awarded 1992.

Affiliation: American Psychological Association, Student Affiliate, 1984 to present.

Honors: National Dean's List, 1987 to 1988; Dean's Honor Roll, 1982 to 1988; President's Honor Roll, 1988 to 1992; Phi Kappa Phi, 1985 to 1986.