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AUTHOR	Laetsch, W. M.; Linn, Marcia C.	
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ABSTRACT

The procedures, major findings, and conclusions of the Adolescent Reasoning Project are summarized in this final report to the National Science Foundation. Eleven different experiments were conducted to investigate the role of naturalistic and laboratory task content on scientific reasoning. Participants involved 1500 seventh, ninth, eleventh, and twelfth graders from three school districts varying in socioeconomic status, proximity to an urban area, and sophistication of course offerings in math and science. The appendix describes the purpose of each experiment and indicates the project report publication number that summarizes the results of the findings. The body of the report presents the integrated results of all the experiments and what the project staff thinks the results mean. Major findings are: (1) students respond to naturalistic and laboratory tasks differently; (2) differences in expectations about the task variables account for much of the variance between laboratory and naturalistic tasks; (3) subjects learn what they are taught about controlling variables and about expectations, but do not readily generalize their training to new situations; (4) scientific reasoning overlaps extensively with general ability, but also overlaps with an aspect of field-dependence-independence identified in the studies. (DC)

Final Report

NSF-RISE SED 77 18914

EVALUATION OF SCIENTIFIC REASONING ABILITY IN NATURALISTIC AND LABORATORY TASKS

W. M. Laetsch - Principal Investigator
Marcia C. Linn - Project Director
Lawrence Hall of Science
University of California - Berkeley
Berkeley, California 94720

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Lawrence Hall of Science
University of California - Berkeley
Berkeley, California 94720

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Final Report: Evaluation of Scientific Reasoning Ability in Naturalistic and Laboratory Tasks

Overview

This report summarizes the work of the Adolescent Reasoning Project (ARP) conducted for NSF-RISE grant SED 77 18914 entitled "Evaluation of Scientific Reasoning Ability in Naturalistic and Laboratory Tasks." Project work is summarized in two ways. The sections called "Major Findings" and "Conclusions," integrate our results and indicate what we think they mean. The appendix called "Con[illegible]f Proposed Research" describes the subjects and the experiments. The final report also includes a project bibliography and select project publications.

Project Personnel

W. M. Laetsch,	Principal Investigator	1978-1980
Marcia C. Linn	Director, Adolescent Reasoning Project	1978-1980
Steven M. Pulos	Research Psychologist	1978-1980
Cathy Clement	Research Assistant	1979-1980
Michael Miller	Research Assistant	1978-1979
Jerie Robertson	Research Assistant	1978-1979
Christine Bradford	Research Assistant	1978-1979
Kevin Delucchi	Research Assistant	1979-1980
Tina de Benedictus	Post Doctoral Fellow	1979-1980
Janet Rocha	Undergraduate Assistant	1979-1980
Harbour Fraser	Undergraduate Assistant	1978-1979
Lois Foley	Assistant Researcher	1978-1979
Diane Alexander	Secretary-Interviewer	1978-1979
Gale Lambert	Secretary-Interviewer	1978-1979
Pat Sullivan	Secretary-Interviewer	1979-1980

Major Findings

The Adolescent Reasoning Project (ARP) was funded by the National Science Foundation (RISE-SED 77-18914) to investigate the role of naturalistic and laboratory task content on scientific reasoning. Most science instruction uses laboratory problems. We set out to determine whether inherent differences between laboratory and naturalistic problems would limit the impact of classroom science instruction on naturalistic problem solving.

We conducted eleven experiments, administering over 4,000 hours of group and individual tests to over 1,500 subjects. Over 35 articles and over 15 meeting presentations summarize our findings.

Our major findings are: a) students respond to naturalistic and laboratory tasks differently, b) differences in expectations about the task variables account for much of the variance between laboratory and naturalistic tasks, c) subjects learn what they are taught about controlling variables and about expectations, but do not readily generalize their training to new situations, d) scientific reasoning overlaps extensively with general ability, but also overlaps with an aspect of field-dependence-independence identified in our studies.

These results suggest that subjects often fail scientific reasoning tasks by considering only the variables they think are important. Subjects ignore variables mentioned by others, or present in the experimental situation which they consider unimportant. Instruction can help subjects develop better expectations about the variables and consequently perform better.

Scientific reasoning appears to be composed of general ability and an aspect of field-dependence-independence which we identified called Familiar Field. Scientific reasoning may be difficult to teach just as general ability is difficult to modify. Familiar Field appears to measure the ability to select from among familiar competing strategies. Scientific reasoning instruction might focus on techniques to help students select from among plausible alternative strategies.

We elaborate our major findings in the next sections. Implications of these findings are also presented.

Naturalistic and Laboratory Tasks

Our research revealed overall differences in reasoning on laboratory and naturalistic tasks (e.g., Pulos & Linn, ARP-8; Clement & Pulos, ARP-29[1]). Once general effects were established, specific explanations for these effects were sought.

Role of Expectations in Reasoning Performance

We found that subjects' expectations about the variables in laboratory and naturalistic tasks differed and these expectations accounted for much of the difference in performance. By expectations, we mean beliefs concerning which factors influence problem outcomes and how that influence occurs. For example, many adolescent reasoners inaccurately expect the weight of the bob to influence the oscillation of the pendulum. Thus, reasoners' expectations about the pendulum influence performance.

Our emphasis on expectations contrasts with Piaget's emphasis on logical strategies (e.g., Linn, ARP-28). Our research examined how expectations influence complex reasoning tasks such as those studied by Inhelder and Piaget (1958). We are concerned with when an available logical strategy is applied and with why available logical strategies are not always applied.

Our contention is that errors in reasoning often reflect expectation-based misunderstandings. Subjects fail to control for the material of the

[1] Project publications are referred to by ARP-numbers. These refer to project reports listed by number in the Adolescent Reasoning Project List of Publications which is attached.

rod in Bending Rods because they expect "all metal rods bend the same". We have identified specific expectation-based errors in reasoning and used these to gain a precise understanding of reasoning performance. (See Linn, ARP-28, for a more detailed discussion of this point.)

In contrast, Piagetian research and most replications confound task expectations with strategy, e.g., using a balance beam to measure proportions and bending rods to measure controlling variables. In addition, studies of scientific reasoning have, by and large, been conducted using tasks from physics, thus ignoring possible expectations associated with physics knowledge. Expectations are real, but not frequently investigated in Piagetian-based research.

In these studies we refer to the variables that the subjects consider in solving the problems as the <u>subjects' expected variables</u>. The variables included in the task are called the <u>experimenter's comprehensive variables</u>.

Responding to evidence (e.g., Lovell, 1961) that formal reasoning was less prevalent than he anticipated, Piaget (1972) suggested that individuals might exhibit formal reasoning in their area of expertise. Piaget suggested that, for a given problem, experts in the field would reason better than novices. Applying Piaget's notions about expertise to our ideas about expectation-based influences on reasoning, we hypothesized that experts would expect more variables to influence the outcome of a problem in their area of expertise than would novices. We investigated this hypothesis in a series of studies.

Pulos and Linn (ARP-8) investigated the influence of expertise on reasoning. An ecologically valid comparison was possible. One group of subjects were experts in fishing because they lived adjacent to a river delta; for them, variables influencing catching fish were familiar. Another group were experts in solving physics problems because they had taken experiential science courses; for them, variables influencing a physics task like Bending Rods were familiar. Both groups responded to controlling variables tasks about fishing and tasks about physics. For each group, one task had familiar variables. In addition, both groups took a third task which was parallel to the other two but had artificial content involving space people on a fictitious planet. Variables in this task were unfamiliar for both groups. In each task, subjects designed controlled experiments. All three tasks could be solved without any expertise in the area. There was a significant effect for expertise on performance: river delta subjects performed better on Fishing than on Bending Rods while experiential science subjects performed better on Bending Rods than on Fishing. There were no differences in performance on the artificial task. If we assume that expectations vary with expertise, these results suggest that expectations influence controlling variables performance.

Linn and Swiney (ARP-22) investigated the relationship between twelfth grader's expected variables and the variables they correctly utilized on a controlling variables task. The subjects' expected variables were measured by having subjects examine the task apparatus and name the variables they expected would influence the outcome. Subjects were presumed to name their expected variables. Subjects were then told the experimenter's comprehensive variables (variables the experimenter thought were important). The variables correctly utilized by the subject were those variables correctly controlled or investigated in three experiments. Comparison of the subject's expected variables and the variables the subject correctly utilized revealed that subjects utilized their expected variables significantly more often than other variables. Subjects appeared to answer the controlling variables questions as if only their expected variables were important--subjects ignored the experimenter's comprehensive variables.

Linn, Clement, and Pulos (ARP-29) extended the findings of Linn and Swiney (ARP-22) using seventh, ninth, and eleventh graders. They hypothesized that expectations would vary with task content. Naturalistic tasks have content from frequently encountered situations such as determining which is the best toothpaste to buy or determining how to get the best gas mileage. Laboratory tasks generally have content from physics such as determining what makes rods bend. In the naturalistic tasks, as in the laboratory tasks, subjects were asked about the design of controlled experiments.

Linn, Clement, and Pulos (ARP-29) measured expectations and found that they differed for laboratory and naturalistic tasks: subjects expected to consider more laboratory task variables than naturalistic task variables. Consistent with the findings of Linn and Swiney (ARP-22), subjects performed best on controlling variables questions when their expected variables closely approximated the experimenter's comprehensive variables. The subjects performed better on controlling variables for laboratory than for naturalistic tasks because their expected variables were more comprehensive than for naturalistic tasks. Expectations strongly influenced reasoning performance: between 8% and 20% of the variance on controlling questions was associated with content.

In general, it appears that subjects reason about their expected variables. Pulos and Linn (ARP-8) found that subjects reason better in their area of expertise presumably because they know more of the variables. Linn and Swiney (ARP-22) found that subjects control their expected variables. Linn, Clement, and Pulos (ARP-27) found that performance on controlling variables tasks reflected the magnitude of the subjects expected variables.

Instructional Interventions

Many programs to encourage better reasoning about complex math- and science-related problems have been tried with limited success (see Levine & Linn, 1977; Linn, ARP-16). Teaching new strategies has been much less successful than teaching new ways to use existing strategies. Piaget (quoted by Hall, 1970) has remarked that instruction in the content-free strategies characteristic of formal reasoning is useless. Many unsuccessful studies attest to this assertion (e.g., Levine & Linn, 1977; Linn, ARP 19).

In contrast, subjects have been taught to control variables on a wider variety of problems (Linn, ARP-16), or to apply proportional reasoning more consistently (Kurtz & Karplus, 1979). Thus, it is possible to differentiate between teaching previously unfamiliar strategies and teaching new applications of available strategies. We investigated instructional interventions designed to alter inaccurate expectation-based rule usage and therefore enhance application of available strategies.

Of course, strategy application cannot occur unless the strategy has been acquired. Instruction which combines strategy training with application training succeeds more consistently than either one by itself (e.g., Linn, ARP-16, ARP-19; Kuhn & Angelev, 1976; Linn, Chen, & Thier, 1979).

Methods for teaching strategy application are not well established. Cronbach and Snow (1977), in their book on aptitude treatment-interactions, report successful instances of teaching strategy application which they call "tuning." Tuning is a form of instruction which helps subjects recognize when to use an available complex reasoning strategy. Examples of procedures which can be classified as tuning include: a) practice items, b) instructions which note the similarity between new items and familiar items, e.g., saying "These items involve computation or proportions", c) instructions which specify what about the problem is most important, e.g., saying, "In these items, first figure out what variable is being investigated, then figure out which variables need to be kept the same."

Results of our studies to change expectation-based rule usage were mixed. Linn and Delucchi (ARP-32) attempted to increase the subjects' expected variables. Their "variables training" explained that people only control variables they expect will influence the outcome, yet other variables may also be important. Subjects did not change their expectations. Subjects probably need more direct evidence that their expectations are incorrect before they will change their expectations.

In a series of studies of the pendulum (Linn, 1977; Pulos & Linn, ARP-3) direct evidence for inaccurate expectations was given. Many subjects based responses to Pendulum on expectations that the weight of the bob and the height of the release point influence oscillation rate. During expectation training subjects conducted controlled experiments to investigate each variable. This direct evidence of inaccurate expectations enhanced performance on the Piagetian version of the Pendulum.

Clement, Linn, and Pulos (ARP-33) attempted to alter expectations about the factors which influence one's blood pressure. They had three conditions: 1) no training, 2) a week-long classroom unit on blood pressure variables, and, 3) a 40-minute individually tutored unit on strategies for controlling variables. They found that the classroom unit on variables changed the subject's expected variables and that the classroom unit on variables plus the individual unit on strategies enhanced the subject's ability to control variables having to do with blood pressure. Performance on related questions suggested that the instruction had rather narrow effects.

In summary, instructional interventions may fail because they do not clarify how strategies can be applied to new problems. Conceivably, subjects need instruction in both variable selection and strategy selection to improve reasoning. Research on tuning and research to alter expectations suggest directions for design of instructional interventions which enhance strategy application.

What Does Scientific Reasoning Measure?

We established relationships between scientific reasoning and commonly studied aptitudes and abilities in order to place our tasks in a broader context. An aptitude model emerged from our work and that of others (e.g., Snow, et al., Note 1; Linn & Kyllonen, 1981; Witkin & Goodenough, Note 2). We describe the model and then show how it applies to our measures of scientific reasoning.

Our research and that of others supports an aptitude model related to Horn and Cattell's (1966) conceptualization of General fluid ability, General crystallized ability and Spatial visualization, augmented by measures of field-dependence-independence as described below. Snow (1980) has done extensive research to show the value of this model in research on reasoning. By establishing the relationship between these commonly studied aptitudes and our new measures we can validate our measures.

Cattell (1971) and Horn and Cattell (1966) identified General crystallized and General fluid ability and later included Spatial visualization; Spatial visualization was thought to be distinct from, but correlated with, General crystallized and General fluid ability for adults. Tests requiring identification of new relationships, such as Letter Series, measure General fluid ability (Gf). Tests measuring the extent of and retrieval of overlearned information, such as Vocabulary, measure General crystallized ability (Gc). Tests requiring mental manipulation of figural material, such as Paper Folding or Paper Form Board (e.g., French, et al., 1962), best measure Spatial visualization (Sv). Snow et al. (Note 1) attempted to replicate Horn and Cattell's (1966) work on Spatial visualization for adolescents, but could not separate Gf from Sv so they labeled the combined dimension General fluid visualization (Gfv). Thus Spatial visualization and General fluid ability formed a single dimension, defined by tests requiring mental manipulation of figural or non-figural material.

Linn and Kyllonen (ARP-21) clarified the relationship between Gfv and Witkin and Goodenough's (Note 2) concept of field-dependence-independence (FDI). Witkin and Goodenough (Note 2) had identified two FDI dimensions. One, cognitive restructuring, was measured by Embedded Figures and closely resembled Snow's Gfv. The other, Perception of the Upright, was measured by the Rod and Frame test and appeared to differ from Gfv. Linn and Kylonnen (1981) combined measures of Gfv and both aspects of FDI. They identified two dimensions. One was similar to Snow's Gfv and included the Cognitive Restructuring tests and was still labeled Gfv. The other was characterized by Perception of the Upright but also included the Weschler Picture Completion test; they labeled this Familiar field (Ff). The Ff dimension was hypothesized to measure strategy selection in familiar situations when competing strategies were available. Thus, two unique dimensions emerged from among General fluid ability, Spatial visualization and field-dependence-independence--these were Gfv and Ff.

Our aptitude model includes Gfv and Ff as well as General crystallized (Gc) which remained distinct from the other two. To investigate our task analysis of expectation-based reasoning performance, we examined how Gfv and Ff relate to reasoning performance. The relationship between our aptitude model and scientific reasoning was established in several studies (e.g., Linn, Pulos, and Gans, 1981, ARP-11; Linn & Swiney, ARP-22; Linn, ARB-5). All these studies revealed a strong overlap between scientific reasoning and general ability (as measured by Gc and Gfv). Several of the formal measures were related to Ff. Two questions emerge: a) Is scientific reasoning a unique ability? and b) What is the role of Ff in scientific reasoning?

Some writers (e.g., Humphries & Parsons, 1980) feel that reasoning about Piagetian tasks overlaps completely with general ability while others feel that there is unique variance in scientific reasoning (e.g., Linn, ARP-9; Linn & Swiney, ARP-22). Our studies suggest that some aspects of scientific reasoning performance reflect unique knowledge. As suggested by Linn and Swiney (ARP-22), unique aspects of scientific reasoning may reflect specific content knowledge.

Many studies have shown a relationship between field-dependence-independence and scientific reasoning including several done by our project (e.g., Linn & Swiney, ARP-22; Linn, ARP-5). Our studies refine understanding of FDI by identifying the Ff dimension and showing that it measures strategy selection in familiar situations for both controlling variables (Linn, ARP-5) and proportional reasoning (Linn & Swiney, ARP-22).

Strategy selection is a common component of scientific reasoning. Relationships between Ff and scientific reasoning may reflect strategy selection. We found that Ff only contributes to performance for formal-reasoning tasks, which are difficult for most subjects. Familiar field appears to tap an aspect of identification of new relationships. As scientific reasoning strategies develop, they come to compete with other incorrect strategies. Thus, Ff appears to be associated with scientific reasoning tasks when there is competition among familiar strategies.

Implications

Following the tradition established by Piaget, research on scientific reasoning has focused on factors emphasized by the theory rather than on expectations about the task variables. Our research suggests that expectations deserve more careful scrutiny. Our research has shown that specific expectations, individual aptitudes, and instructional interventions can all influence performance. Each of these aspects of scientific reasoning suggest directions for educational intervention. Researchers interested in education are encouraged to focus their efforts on these aspects of scientific reasoning performance. For extended discussion of the implications of our findings, see the attached project publications (ARP 19, 21, 28, 36).

These findings, taken together, suggest that researchers should analyze performance at a more specific level than the Piagetian stage. Expectations about task variables are not a part of the Piagetian stage, but influence classroom performance. Diagnosis of specific reasoning errors based on expectations suggest how reasoners progress within stages. Aptitude differences among learners may clarify why some individuals achieve scientific reasoning and others do not. Finally, design and evaluation of instruction focused on specific reasoning errors may clarify why scientific reasoning is so difficult to teach.

Expectations

Investigation of the expectations about task content in scientific reasoning can validate and clarify Piagetian theory. Although Piaget has not focused on specific errors, our research identifies specific errors based on expectations and gives a more precise picture of how reasoners move from one stage to another. Establishing the effect of expectations on reasoning may simplify investigation of theoretical factors. Content-free strategy acquisition must be separated from the effects of content to be investigated clearly.

The role of expectations in formal reasoning deserves scrutiny by science educators because these factors are likely to have practical implications. Educators frequently use research to design curricula. Research which helps curriculum developers anticipate and remediate reasoning errors will enhance science education. As an ultimate goal, research on expectations might help teachers develop skills in diagnosing errors made by students in their classes.

Expectation effects clarify research findings of pervasive inaccurate physics reasoning. McDermott (Note 3) reports inaccurate reasoning about acceleration; Clement (1979) reports inaccurate reasoning about force; Champagne, Klopfer, and Anderson (1979) report inaccurate reasoning about mechanics. If subjects have inaccurate expected variables they might reason inaccurately because they only reason about their expected variables. In the research reported here, subjects considered only their expected variables, thereby omitting important variables. In other situations, by reasoning about their expected variables, subjects might include unimportant variables such as weight as a variable in the oscillation of the pendulum. Thus, studies showing inaccurate physics reasoning may reflect inaccurate expected variables.

Our research also suggests that instruction in laboratory problems is unlikely to generalize to naturalistic problems. Naturalistic tasks are important to insure that science education fosters scientific literacy. Instruction using naturalistic situations would enhance the relevance of the instructional program. It is essential to provide instruction that helps students evaluate expectations about naturally occurring problems. Laboratory tasks may not require such evaluations. Since it is apparent that evaluation of expectations is very important for naturalistic problem solving, efforts to choose problems for science instruction to illustrate the role of expectations would enhance scientific literacy.

These results suggest that educational implications generated from Piagetian theory may be incomplete. Expectations require more emphasis. Consistent with Duckworth's (1979) suggestions for younger children, variability in performance on reasoning problems may not be due so much to lack of developmentally based strategies as to lack of instruction in how to combine expectations and strategies.

Aptitudes

Capitalizing on aptitude-treatment-interactions may enhance the effectiveness of instruction. For example, the Linn (ARP-5) study suggests that subjects who are field dependent should first be taught to control variables in problems without irrelevant information and then specifically taught to identify and eliminate irrelevant information. By carefully selecting examples and in other ways specifically modifying science instruction, educators will ultimately help students of a variety of aptitudes perform better in math and science.

APPENDIX

Conduct of Proposed Research

Our research project conducted eleven experiments involving about 1500 seventh, ninth, and eleventh grade subjects in three school districts. We administered 4000 hours of group and individual tests, analyzed the results and reported our findings in over 35 articles and over 15 presentations at meetings.

Subjects

Subjects were 1500 seventh, ninth, eleventh, and twelfth grade students from Bay Area schools. Our main sample of 900 subjects consisted of approximately 100 students per grade for seventh, ninth, and eleventh grade in three schools. Each study used 90 or more students, ten from each grade in each school. Schools varied in socioeconomic status, proximity to an urban area, and sophistication of course offerings in math and science.

Experiments

We proposed and carried out eleven experiments. The results that we anticipated did not always coincide with the results that we collected. Some of our anticipated results did not materialize while other results fit different interpretations than we expected. Publications describing each experiment have been produced by project personnel. In this section we describe the relationship between our proposed research and our experiments. In the section called "Major Findings and Conclusions," we give our current interpretation of our findings.

Design of Instruments

The project has designed, pilot tested, and validated a wide range of tasks. We have devised or revised over 20 measures of controlling variables which are described in several of our reports (e.g., Linn, Clement, & Pulos, ARP 29). Two of our reports focus on our controlling tasks (Linn, ARP-1; Linn & Rice, ARP-2). Our measure of predicting displaced volume is described in Linn and Pulos (ARP-27). Our measures of abilities and aptitudes are described in Linn and Pulos (ARP-27 and ARP-25).

Experiments I and II

Our first two experiments documented the effects of expectations on naturalistic content and laboratory content controlling variables tasks. By expectations we mean beliefs about how task variables influence task outcome. We found that expectations differed for laboratory and naturalistic tasks and that content accounted for between 8 and 20% of the variance. This research is reported in Linn, Pulos, and Gans (ARP-11), Linn and Pulos (ARP-14) and Linn, Clement, and Pulos (ARP-29).

Experiments III and IV

Two of our studies focused on reasoning in game-like and informal settings. We found few content effects for games with imaginary content. These studies are reported in Pulos and Linn (ARP-6), Pulos and Linn (ARP-7), Pulos and Linn (ARP-8), and de Benedictis (ARP-23).

Experiments V, VI, VII, VIII

These studies focused on factors that might influence reasoning performance, including the effect of the number of variables in the problem (Pulos & Linn, ARP-31), the effect of the salience of the variables (Linn & Swiney, ARP-22), the effects of preconceptions about the variables (Linn & Pulos, ARP-27), and the effect of complexity of task format (Linn & Pulos, ARP-25; Linn, Clement & Pulos, ARP-29).

Taken together, these studies suggested that expectations about problem variables (including salience and preconceptions) consistently influenced performance. Subjects followed clearly definable rules to generate both their correct and their incorrect responses. Format effects such as the number of variables in the task, or the ease in designing a fair experiment also influenced performance. The effects of format were less dramatic than the effects of expectations.

Experiments IX and X

These experiments were preliminary studies of how reasoning about controlling variables could be enhanced. Pilot work indicated the difficulty in changing expectations (Pulos & Linn, ARP-3). A study of training on strategies versus training on expectations met with limited success (Linn & Delucchi, ARP-32). A large-scale study comparing training to alter expectations and training on the design of fair experiments suggested directions for future studies (Clement, Linn, & Pulos, ARP-33, de Benedictis, ARP-26). Two reports integrate current and previous studies of instructional interventions to suggest how scientific reasoning can be altered (Linn, ARP-16); Linn, ARP-35).

Experiment XI

This study focused on the aptitudes and abilities required to solve complex-reasoning tasks. We investigated the field dependence-independence construct (Linn, ARP-5; Linn, ARP-4; Linn & Kylonnen, ARP-21). We related measures of previously studied aptitudes and abilities to a variety of reasoning tasks (e.g., Linn, Pulos, & Gans, ARP-11; Linn & Swiney, ARP-22; Linn & Pulos, ARP-25, ARP-27). Aptitude and ability measures clarified what our new tasks measured and suggested why some tasks were failed.

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