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Q-Test of Undergraduate Epistemology and Scientific Thought: Development and Testing of an Assessment of Scientific Epistemology

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Abstract**—**The QUEST is an assessment of scientific epistemic beliefs and was developed to measure students' intellectual development in regards to beliefs about knowledge and knowing. The QUEST utilizes Q-sort methodology, which requires participants to rate the degree to which statements describe them personally. As a measure of personal theories of knowledge, the QUEST instrument is described with the Q-sort distribution and scoring explained. A preliminary demonstration of the QUEST assessment is described with two samples of undergraduate students (novice/lower division compared to advanced/upper division students) being assessed and their average QUEST scores compared. The usefulness of an assessment of epistemology is discussed in terms of the principle that assessment tends to drive educational practice and university mission. The critical need for university and academic programs to focus on development of students' scientific epistemology is briefly discussed.

Keywords**—**Scientific epistemology, critical thinking, Q-sort method, STEM undergraduates.

I. Introduction

AS teachers of scientific content and methodology, we often find students who excel at skills essential for success in a university environment. These include the ability to learn field-specific knowledge and methods as well as the application of that knowledge and those methods to novel problems. Students may even be capable of developing generalizable skills such as critical thinking and communicating scientific knowledge to lay populations. While those learning outcomes are, and will remain, important, a broad aim of scientific education should be the development of students' beliefs toward a scientific epistemology. This is a call for a new paradigm in scientific pedagogy focused on developing the epistemological disposition of students toward a scientific ethos. Critical to this new paradigm is the recognition that epistemological beliefs are central to how students, and the broader public, understand scientific knowledge and how they use that knowledge to navigate the complexities of their world. One example of this fundamental role of epistemological beliefs is a student who understands the conditions, processes, and skills of critical thinking but does not apply those skills to issues such as global climate change, origins of the universe, or issues of transnational immigration. If students do not have underlying epistemological beliefs that lead them to utilize scientific, critical thinking approaches to issues such as climate change or national immigration policies, they are likely to arrive at limited, short-sighted, and potential destructive solutions. Teaching only the methods and skills necessary to successful scientists without also teaching the worldview or ethos of successful scientists equips students with only part of the necessary competencies for professional and personal success. Knoll describes this intellectual maturity as students moving from ignorant certainty to intellectual confusion [1].

When considering epistemic beliefs, Hofer [2], [3] theorizes that personal epistemic beliefs, called personal theories, consist of 4 domains including "(a) knowledge is simple versus complex, (b) knowledge is certain versus in a state of flux, (c) whether knowing is justified on the basis of dualistic, multiplistic opinions, or evaluative standards of evidence, as well as (d) the degree of reliance on authority to judge the veracity of knowledge claims [4]." Based on these components, or similar dimensions, researchers have theorized models of personal theories of knowledge and knowing from a developmental prospective. These models include Perry's [5] model of intellectual development, women's ways of know proposed by Belenky and her colleagues [6], King-Kitchner's model of reflective judgment [7], and the epistemological development model proposed by Baxter Magolda [8]. Although these models have a different number of development levels and provide varying specificity and sensitivity, models of epistemic maturity.

Most of the theoretical and empirical work examining epistemic beliefs has relied on qualitative, ethnographic methodology. This body of published work has provided a rich understanding of and framework for continuing assessment of epistemological beliefs. The current study builds on previous research for the development and testing of the QUEST (Q-test of Undergraduate Epistemology and Scientific Thought) instrument for use with undergraduate students in STEM disciplines. Students enrolled in their first science and math courses are often most anxious about mathematical operations. However, course difficulties are as likely to arise from uninformed or negative epistemological dispositions toward the scientific ethos underlying scientific thought and statistical processes.

To examine dispositional attitudes toward scientific thinking, a modified Q-methodology assessment tool was developed using 34 statements related to scientific ethos and reasoning. Q-methodology involves having participants read through a series of statements, typically presented on small

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index cards, related to a specific "condition of instruction." The current study examined the development and testing of the QUEST instrument for use with undergraduate STEM students. Unlike traditional Likert-type scales, the QUEST assessment requires respondents to make relative judgments about the extent that each statement describes their way of thinking and dispositional beliefs about knowledge and ways of knowing. The use of ranking, rather than the typical Likert-type rating scale, representing agreement with individual statements, is meant to capture the reality that people think about ideas in relation to other ideas, rather than in isolation.

Q-sort methodology, first developed by physicist and psychologist William Stephenson [9], involves the development of a list of statements that are read and placed in a forced distribution along a scale representing the degree to which each statement describes the participant. This statement sort results in scores for each statement and allows for assessment of the subjective (or relative) rating for each statement. Traditional quantitative instruments measuring people's level of agreement with statements assess absolute levels of agreement. The Q-sort method assesses participants' relative level of agreement to the statements included in the instrument. Therefore, participants cannot "strongly agree" or "strongly disagree" with every statement. Rather, participants must make subjective judgments about their relative level of agreement since they are forced to sort the statements into a predetermined distribution.

By requiring participants to respond (or sort) the statements into a forced distribution, their *subjective* ratings can be measured. In other words, participants are required to make relative judgments about the descriptive nature of each statement. While more than 2 statements may describe the participant to a large degree, participants must make a subjective judgment about which statements are *more* descriptive than other statements. This allows people to best represent their actual dispositions or beliefs by requiring reflection on the relative valance of each statement.

Q-methodology has been employed to examine and assess a wide range of psychosocial and cultural constructs across a wide range of settings with varying populations. Some of these applications of Q-methodology include: an examination of pre-service preschool teachers' beliefs related to children, use of in-class discipline, and teaching practices [10]; patient and caregiver needs in fragile-X associated tremor/antaxia syndrome [11]; comparison of beliefs related to the components of the "ideal marriage" [12]; and use as both an assessment and educational tool for social workers completing continuing education courses [13].

In addition to providing an assessment tool for the subjective beliefs and attitudes of participants and a means of comparing subjective beliefs across populations, Q-methodology has also been utilized to assess contrasts between an individual participant's beliefs and some referent. Preskitt et al. [14] reported the use of Q-sort methodology by public health home visitors to prioritize quality measures for home visits. Public health workers providing in-home client visits used the Q-sort method to establish subjective, personalized priorities of the system-wide quality measures. They then prioritized quality measures indicted by the specific delivery model they utilized. Delivery models included Home Instruction for Parents of Preschool Youngsters (HIPPY; training for parents of preschoolers), Nurse Family Partnership (NFP; nurse visiting for parents of prenatal to 2-year-olds), and Parents As Teachers (PAT; training for parents of prenatal to 5-year-olds). Results demonstrated that prioritization of quality improvement goals varied between system-wide and the delivery models. This study highlights the usefulness of Q-methodology for within-participant comparisons between different referents or standards.

An additional value of the Q-methodology is that it allows researchers to make within-participant comparisons between multiple elements or components of the same concept or person. One application of this use of the Q-sort examined 33 either favorable or unfavorable images of a politician [15]. Researchers first instructed participants to complete the Q-sort of attributions about the politician after viewing the favorable photos. After the favorable Q-sort was complete and participant responses recorded, researchers administered the Q-sort again, this time in response to unfavorable images of the politician. Result of the study showed differential attributions but also interpretations of the politicians based on the image viewed. This degree of sensitivity would be difficult to ascertain with traditional measurement tools.

One clear advantage of Q-methodology compared to traditional Likert-type scales is that Likert-type scales result in lower overall mean scores when tested against Q-method scales measuring situational characteristics. Using the Riverside Situational Q-sort (RSQ), Frascona [16] designed an experimental manipulation of participants' mood and testing method on characterizations of experimental situations. Participants were randomly assigned to a method condition, either Q-sort or Likert, and a mood condition, positive or negative. After participants were induced into the assigned mood by a brief video, they were presented with a second video depicted a first-person perspective of the participant and a friend walking down the sidewalk past a small gathering of people on a college campus. The assigned measurement method (Q-sort or Likert) was administered to the participants.

Results showed that Likert-type scales resulted in higher average rating scores than Q-sort scales for items assessing situational *cues*, which describe an objective physical element of the situation. For items assessing situational *characteristics*, which are elements of situations open to interpretation, the Q-sort scales had higher average scores (See [17] for a review of research on situational cues versus situational characteristics). This provides evidence to the greater sensitivity of Q-sort methodology to subjective judgments requiring interpretation such as epistemic beliefs. Other researchers have reported similar sensitivity differences between traditional Likert scales and Q-sort scales [18], [19].

The sensitivity to differences between the two measurement methods requires additional care to be taken when generating the Q-sort item statements. As noted by [12], "…if an individual respondent positively relates to a majority of the statements, this information is lost when conducting the Q sort. … One way to counter this would be to construct the statements to be primarily neutral, rather than allowing the majority of the statements to be stated in a positive sense….” This issue is addressed in the current study be creating half of the statements as supportive of and half of the statements as unsupportive of scientific epistemology.

If statements are well written, have face validity, and an equal number are written as supportive of the construct and half are written as unsupportive, the Q-sort provides one final advantage over traditional Likert scales. Likert scales are particularly susceptible to acquiescence bias and social desirability. Acquiescence bias is evident when respondents have the tendency to agree with survey statements regardless of the content of the statement. Social desirability occurs when respondents report their level of agreement in a manner that matches the social or cultural expectation, in an attempt to appear similar to the majority or predominate culture. Acquiescence bias and social desirability are particularly prevalent when examining beliefs about scientific epistemology in the university environment. Students can be more likely to agree with the viewpoints of their professors and mentors simply because it is easier to consent than to dissent. Likewise, it is highly likely that students will not want to appear “out-of-step” with the prevailing culture of STEM disciplines. This makes it likely that students will agree with statements affirming their membership in the scientific hegemony even though they may disagree, possibly on the basis of their religious beliefs. Q-methodology requires respondents to answer with a degree of distinction between statements, diminishing acquiescence bias. While respondent may still sort statements in a manner agreeable with the dominate cultural expectation, this type of response pattern is less likely because of the forced distribution and multiple rereading of the statements. This approach can result in the respondent disagreeing with at least some of the statements not supportive of the perceived cultural hegemony [20].

II. METHOD AND QUEST INSTRUMENT

A. QUEST Development

The QUEST Assessment, or the Q-assessment of Undergraduate Epistemology and Scientific Thinking, was developed based on a thorough review of literature related to scientific epistemology and critical thinking, based on the models on epistemological development discussed in [2] [3] and [4]. This review resulted in the development of 34 statements concerning personal theories of knowledge and knowing. Half of the statements (i.e., 17 item) were supportive of scientific epistemology such as “I question the accuracy of information presented by people in positions of authority” and “I value scientific evidence over religious belief.” Of the 34 statements 17 were unsupportive of scientific epistemology including “I believe that religious scripture (e.g., Bible, Koran, Torah, etc.) can inform me about scientific questions such as the origins of the universe” and “I use intuition to make decisions about life.” These statements were reviewed for clarity and face validity as well as being compared against statements found in the research literature reviewed (See Appendix A).

The QUEST Q-sort distribution is represented in Fig. 1. This scoring distribution had scores of -4 (least descriptive of the participant) to 4 (most descriptive of the participant). Participants were instructed to sort the statements by alternating between statements “most descriptive” and then “least descriptive” of their beliefs until all statements were placed in distribution (see Fig. 1).

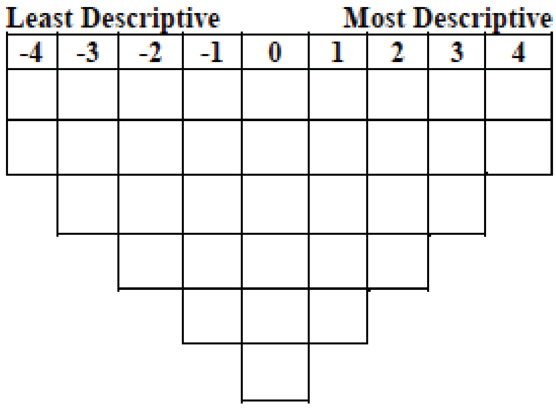

Fig. 1 QUEST scoring distribution

B. QUEST Q-sort and Scoring

Appendix B provides a transcript of the conditions of instruction for the QUEST. The QUEST involved two rounds of sorting; the first required participants to read each statement and assign it to one of three piles based on the general degree to which the statement described the respondent. Participants were asked to read through all 34 statement cards and place the statement card in one of three piles. The pile of statement cards on the right-hand side of the scale should be statements that “describe your beliefs more,” the pile on the left-hand side should contain statement that “describe your beliefs less,” and those statements in the middle pile should be statements that they were “unsure about describing their beliefs.”

The second sorting procedure required the participants to reread all of the statements in the “describe beliefs more” pile and select those two statements cards that *most* described their beliefs. They were then instructed to reread all of the statements in the “describe beliefs less” pile and select those two statements that *least* described their beliefs. This procedure continued during succeeding sorting rounds, alternating between more descriptive and less descriptive belief statements selected from the corresponding first sort piles. Participants were instructed that if there were not the required number of statements in the corresponding pile, they should reread all of the statement in the “unsure” pile and select the appropriate number of statement cards to complete the distribution required during that sorting round. For example, during the fifth sorting round, participants were instructed to reread all of the statement cards in the “more descriptive” pile and select the four statements that most describe their beliefs. If the participant did not have 4 statement cards left in the “more descriptive” pile on the right-hand side of the distribution they were instructed to reread and select the needed number of statement cards to have a total of four statements sorted under the scale score of +2. Therefore, sorting Round 1 resulted in the selection of the two most descriptive statements, Round 2 the two least descriptive, Round 3 the three most descriptive statements, Round 4 the three least descriptive statements and so on. Sorting continued in this manner until all statements were placed along the 9-point scale (ranging from scores -4 to 4).

Each statement is assigned an item number that is recorded in the scoring distribution, corresponding to the statement sorting of participants. Each item is then assigned the value corresponding with the respondents’ belief in the statement as descriptive of them. As score anchors participants are told to select two statements that are the most descriptive of their beliefs resulting in possible scores of -4 to +4 for each item. The sum of Unsupportive item scores is subtracted from the sum of Supportive item scores (i.e., Supportive-Unsupportive). QUEST scores are positive if the participants have greater scientific epistemic beliefs and negative if participants have less scientific epistemic beliefs. Participant QUEST scores can range from 60 (greatest endorsement of scientific epistemology) to -60 (greatest endorsement of unscientific epistemology).

C. Preliminary Testing

Two samples of undergraduate students completed the QUEST Test at the beginning of the Spring semester. One sample consisted of primarily 3-year students who had completed the undergraduate behavioral statistics and research course required of all Psychology majors (i.e., advance sample). The second sample included students enrolled in the undergraduate behavioral science statistics course (i.e., novice sample). The total sample included 8 females and 8 males from a medium-sized university located in the Southeast region of the US. Location is an important consideration since a fundamental, evangelical Christian culture predominates in this region of the United States.

Follow-up data collection and analysis will include pretest-posttest comparisons across academic level. This quasi-experimental design will allow testing of the hypotheses that the main effects for academic level (novice vs. advanced) and for testing period (pretest vs. posttest) will both be significant. It is also hypothesized that the interaction between academic level and testing period will be significant due to greater change in QUEST scores from pretest to posttest for novice students compared to advanced students.

III. Results

Demonstration that the QUEST Test has utility for the measurement of scientific epistemology was demonstrated by this preliminary study. Comparisons between the two samples should be viewed as a demonstration of the potential use of the QUEST in establishing the development of students’ scientific epistemology and *not* to draw conclusions about the effectiveness of the specific statistics course reported here. To avoid misinterpretation or over-interpretation of these results, no between group statistical testing was conducted. Individual QUEST scores were calculated by taking the sum of scores (with a range of -4 to +4) for items supportive of scientific epistemology and subtracting the sum of items unsupportive of scientific epistemology. Thus, the QUEST scores equation is, *Supportive Epistemic Beliefs Score - Unsupportive Epistemic Beliefs Score*. This approach results in scores ranging from -60 (unscientific epistemology) to +60 (scientific epistemology). Results showed that the sample of 8 “novice” students had a mean QUEST score of 1.88 compared with the sample of 8 “advanced” students who had a mean QUEST score of 15.32 (See Fig. 2).

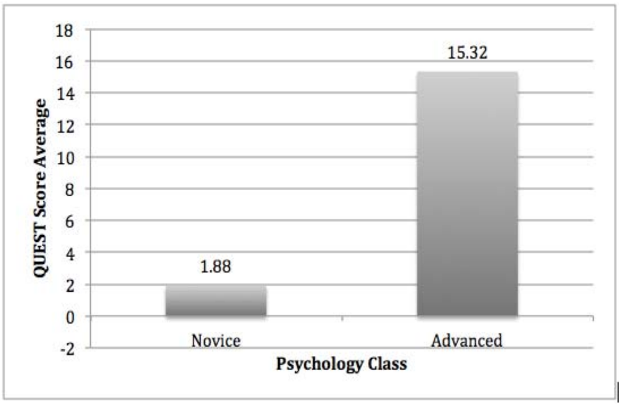

Fig. 2 Average QUEST scores for Novice (lower division) and Advanced (upper division) psychology students

IV. Conclusions

The current study demonstrates the utility of the QUEST Test for the assessment of scientific epistemology among college students. Given that the goal of science education should include development of students’ ethos about the nature of knowledge and what it means ‘to know,’ efforts should be made to assure that graduates are equiped with scientific competencies that extend beyond discipline-specific content and methodology. As argued by Hofer [4], education consists of personal theories of knowledge. These personal theories are integral to the development process of successful scientists.

Scientific epistemology is the foundation of STEM education. Discipline-specific content is constantly being tested, modified, contradicted (or supported), and reimagined. In fact, this process of hypothesize-testing-modification is one of the basic principles underlying the scientific method. If STEM education provides only content knowledge without the tools for discovering and constructing new knowledge in the field, then faculty members and universities are generating graduates who will be “obsolete” in 7 to 14 years.

The half-life of knowledge is a concept first proposed by Fritz Machlup in 1965 [21]. Argued as analogous to the half-life of an isotope, knowledge half-life is the time it takes for knowledge in discipline to become obsolete or proven wrong.

While little research has been conducted to establish knowledge half-life times in differing disciplines [22], a recent comprehensive statistical analysis of scholarly references and citations published across multiple disciplines since 1968 demonstrated that knowledge half-life in STEM disciplines varies from 7.15 years in psychology to 13.07 years in physics [23]. The author used the time period of cited research as an indication of the average number of years that published knowledge remains relevant in the fields of physics, economics, mathematics, history and religion. This demonstrates the importance for STEM educators to develop scientific thinkers who can continue the pursuit of knowledge in their field.

Assessment often drives practice and policy [24], [25]. If the goal of STEM educators should be to develop "science thinkers," then assessment is critical to the inclusion of scientific epistemology into the classroom as well as the university boardroom. The QUEST represents an instrument to facility this transition from philosophy to policy to practice. The current study demonstrates that this difficult-to-assess construct of epistemology can be measured and that the preliminary data suggest the QUEST has construct validity. Continued testing of the QUEST is necessary to further develop the content validity of statement items, assess reliability, and examine external validity to and across fields of study.

The QUEST Assessment represents a promising tool to help focus attention on this critical component of science education by providing a useful assessment of scientific epistemic beliefs. Having quality assessment of scientific thinking will encourage faculty and university administration to prioritize goals related to the intellectual development of students along with discipline-specific skills. Potential employers as well as graduate schools rank scientific epistemic beliefs and scientific thinking as one of the most valuable competencies for college graduates [26]. Demonstrating methods of measuring these competencies and predispositions is a crucial first step to reprioritize higher education to the goal of producing life-long thinkers and learners. It is only if we can establish good assessment of crucial skills, competencies, and predispositions that we as educators can argue for the inclusion of those goals in higher education policy.

Appendix A

QUEST Statement Items

Statements Supportive of Scientific Epistemology

1. I reject religious ideas that conflict with scientific and rational principles
2. I make decisions based on objective evidence.
3. I think that the universe was formed by what is commonly called the 'Big Bang.'
4. I think that evolution is responsible for biological diversity.
5. I believe it is important to question information.
6. I observe social situations in order to arrive at possible explanations for human behavior.
7. I construct tentative explanations about things that need to be explained.
8. I decide about the accuracy of hypotheses based on evidence.
9. I question the accuracy of information presented by people in positions of authority.
10. I use logic to solve problems.
11. I come to evidence-based conclusions and solutions for problems.
12. I think open-mindedly when assessing practical implications of scientific evidence.
13. I communicate effectively with others in proposing solutions to problems.
14. I clearly identify my personal point of view on controversial issues.
15. I evaluate strengths and weaknesses of differing viewpoints on controversial issues.
16. I value scientific evidence over religious belief.
17. I use reason to arrive at answers to questions.

Statements Unsupportive of Scientific Epistemology

1. I ignore other points of view on controversial issues.
2. I accept the accuracy of expert-opinion as evidence to explain phenomena.
3. I accept traditional answers to explain the natural world.
4. I believe in traditional stories to explain natural phenomena.
5. I believe in supernatural causes to explain natural phenomena.
6. I value religious beliefs over scientific evidence.
7. I believe that religious scripture (e.g., Bible, Koran, Torah, etc.) can inform me about scientific questions such as the origins of the universe.
8. I value explanations of natural phenomena offered by my religious leaders.
9. I believe information presented by people in positions of authority.
10. I believe that personal experience is the best source of knowledge.
11. I use intuition to make decisions about life.
12. I think that astrology can accurate predict one's life path.
13. I think that a supreme being (e.g., God) created the universe.
14. I reject ideas that contradict religious scripture (e.g., the Bible, Koran, Torah, etc.).
15. I generally go with my "gut" feeling to solve problems.
16. My first opinion on a topic usually never changes.
17. I believe that dreams are spiritual messages (e.g., from God) that can guide decisions in my life.

Appendix B

QUEST Conditions of Instruction

"Science" should be understood to mean those fields of study that use the scientific method such as biology, physics, chemistry, as well as the behavioral and social sciences. The words "natural phenomenon" and "natural phenomena" should be broadly understood to mean all events we experience in our lives. Examples of these range from thunderstorms, the color of birds, diseases such as cancer, psychological disorders such as depression, and falling in love. They also mean events that we do not directly experience but are part of universe such as movements of planets, origin of the universe, or the nature of black holes. Thus, "natural phenomena" should be broadly understood to mean, human, earthly events and experiences as well as events and experiences throughout the universe.

"Religion" should be understood to mean your faith tradition and includes both organized, institutional religious groups such as a church, denomination, mosque, synagogue, etc. It also includes faith beliefs that involve spirituality but may not involve a formalized religious organization. An example of this would be an individual practice of spirituality that includes beliefs about natural phenomena.

This assessment is a measure of *your* attitudes toward the 34 statements on the cards. There are no right or wrong answers anymore than there is to the statement "Chocolate ice cream is my favorite dessert" or "Red is my favorite color." Please respond with *your* opinion.

First Sort:

Please read through the statement cards and place the statement card in one of three piles. Place those statements that "most describe" you on the right side of the scale, those statements that "least describe" you on the left side of the scale, and those statements that you are unsure about describing you in the middle of the scale.

Second Sort:

Now re-read those statements in the pile on the right side of the scale and select those two (2) statements that describe you the most. Place those statements under the score "4." If there are not two statements in the left side pile, select one from the middle pile. The order of these two statements does not matter.

Next re-read the statement cards in the pile on the left side of the scale and select those two (2) statements that describe you the least. Place those statements under the score "-4." If there are not two statements in the left side pile, select one from the middle pile. The order of these two statements does not matter.

Now re-read the statements in the pile on the right side and select those three (3) statements that describe you the most. Place those statements under the score "3." Again, you can select from the middle "unsure" pile if you don't have 3 statements in the right side pile. Again the order of these statements does not matter.

Next re-read the statement cards in the pile on the left side of the scale and select those three (3) statements that describe you the least. Place those statements under the score "-3." Again, you can select from the middle "unsure" pile if you don't have 3 statements in the left side pile. Again the order of these statements does not matter.

Now re-read the statements in the pile on the right side and select those four (4) statements that describe you the most. Place those statements under the score "2." Remember, you can select from another pile if you don't have 4 statements in the right side pile. Again the order of these statements does not matter.

Next re-read the statement cards in the pile on the left side of the scale and select those four (4) statements that describe you the least. Place those statements under the score "-2." Remember, you can select from another pile if you don't have 4 statements in the left side pile. Again the order of these statements does not matter.

Now re-read the statements from the remaining statements and select those five (5) statements that describe you the most. Place those statements under the score "1."

Next re-read the statement cards and select those five (5) statements that describe you the least. Place those statements under the score "1."

Now place the remaining statements in the middle of scale under the number zero.

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