

The Level of Scientific Methods Use in Computing Research Programs

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Abstract - The research investigates the level to which scientists' use scientific methods in computing research programs. Data was collected from a representative sample of researchers in the field. The findings show that the present research programs are more driven by the market forces. Innovations come up as a consequence of satisfying the market calls but not necessarily a result of advancement in basic science. Researchers' investigations are driven by three characteristics; proof of performance, concept and existence.

Also noted from the study, some researchers lack a clear distinction between the methods. They tend to mix methods in their research programs as long as the industry accepts their outcome artifact. Consequently, there is lack of a clear curriculum to instill such methodological concepts at graduate level in some of the computing schools.

Keywords: Scientific methods, computing, methodologies, artifact, computer science

I. INTRODUCTION

Computer as an artifact, its recent development and use has entrenched all sectors of human life. The relationship and effects of this artifact's usage in human's life (let it be social, psychological, healthy, economical, etc..) are yet holistically to be determined. Its popularity that has super passed any other artifact in the history of humanity leads us to investigate the rationale behind its development drive. Is it because of the underlying science or the novelty in the artifact? What, and how special are the scientific methods used by scientists in *research program* that have lead the computer *program of research* more progressive than others? How science is computing and what is its level of science classification? These questions raised our curiosity of conducting an investigation into the use of scientific methods in computing and the level of adherence to such methodologies by researchers in the respective fields of computing.

In this paper we describe our findings, and it is organized as follows. In the next section take a look at the *universal methods* for science in brief, from the classical view of theory of science to the modern science. This gives a background of the classical methods that acts as our spring board to exhaustively discuss the modern scientific

methods in context of the today's scientific research programs in general discussed in section III. Narrowing the scope, section IV discusses the scientific methods in computing. Section V analyzes and discusses the results obtained from *scientific methods use survey*. The results of the survey identify the extent individual researchers use scientific methods in conducting their research programs, and their views towards the use of such methods. We present our conclusive findings in section VI.

II. BACKGROUND

A. Profound Theories on Science

From the works of Popper [1], Kuhn [2], Lakatos [3], and Chalmers [4] much is written on science and scientific methods for its advancement. Drawing a line of demarcation between science and non/pseudoscience is still a topic of debate in the echelons of philosophers of science. Though there are inconsistencies and contradictions on the criteria of drawing the line of demarcation (i.e, criteria on judging what is science and what is not), they all agree that disciplines like creation science, parapsychology, astrology, etc. are not science.

In [1], Popper used terms like "*Metaphysics*" in a degrading way of distinguishing science from pseudoscience. He was not contented with *empirical method*, which is essentially *inductive*, proceeding from observation or experiment. He felt that such a method would not obviously disqualify pseudo-science from good science. His endeavors were to distinguish between a genuinely empirical method from non-empirical or even a pseudo-empirical method. In his view, the results of observational test should be able to predict even before the test is made, as long as the underlying theory is scientifically grounded. In this way "scientific grounded" is accompanied with a 1000+ experience. If observation shows that the predicted effect is definitely absent, then the theory is simply refuted, hence non-scientific. Therefore it cannot claim to be backed by empirical evidence in the scientific sense. In brief, Popper sums up by saying that "*the criterion of the scientific status of theory is its falsifiability, or refutability, or testability*". In context of

Popperian argument of refutability, we note that hypotheses (statements, propositions) should be logically falsifiable, i.e. their negation should be provable in some calculus devised by the theory. However the risk with it, which has been criticized by many, is that one false prediction leading to such falsification is a very strong condition for research rendering it not scientific.

In [2] Kuhn is subjective where Popper is objective. He argues that scientific statement (hypothesis, or conjecture) are tested for consistency, taking current theory as a premise. Unlike Popper, he believes that real challenge to the theory are extremely rare, called forth only by a crises in the field or a rare strong competitor theory. Most of the science practiced is normal science not the extraordinary science. The aim of practicing scientist is to see whether they can solve problems by using these accepted theories in conjunction with other assumptions and models.

In respect to whether the practicing scientist fails to get the right answer, Kuhn terms it as a puzzle-solving aspect of the normal science. A failure is put on the practicing scientists like a student fails to answer an exercise at the back of the physics text book, but not to the theory. A normal science is practiced within a paradigm which distinguishes it from non-science. He acknowledges that all paradigms will contain some anomalies, but that does not call for its falsification. It is during this period of normal science that provides the opportunity for scientists to develop the esoteric details of the science.

Therefore we note that with Kuhn's classical view of the science, there are frameworks in which scientific research questions are investigated. These frameworks clearly distinguish what is a science and what is not a science. A practicing scientist within a given framework is expected to face challenges of forth and back during the progress of the investigation.

In [3] Lakatos is not satisfied with Popperian argument of refutability (falsifiability, testability) as a solution to the demarcation problem, neither does he agree with Kuhn's suggestion that scientific revolutions are largely irrational affairs. Despite of the difference, like Kuhn, Lakatos portrays a scientific activity as taking place in a framework which he coined a *research program*. He proposes that within a research program science is constituted by a *hard core* (the fundamental principles that define the characteristics of the program), *protective belt* (many auxiliary hypotheses that protect the hard core), plus a *positive heuristic* (that tells the scientists how to solve problems using the theory and how to respond to anomalies by revising the protective belt). That is to say, the *hard core* is unfalsifiable, scientist work within the realm of the *protective belt*. The merit of the research program is indicated by the extent to which it leads to novel predications that are confirmed. Failure to confirmation does not mean abandonment of the research program but an

indication that more work is needed to be done on supplementing or modifying the protective belt. In addition, it offers a program of research, i.e. the positive heuristic coherency helps to guide future research directions of the program.

The methodology of scientific research program in this context involves expansion and modification of its protective belt that is achieved through addition and articulation of various hypotheses. Such modifications or additions must be independently testable. That is, individual scientist or group of scientist can modify or add to the protective belt in any way they deem right, provided such moves leads into new tests and hence possibility of novel discoveries.

Like Kuhn, Lakatos also argued that researchers should look at the history of science if a theory of science is to make sense. That is, theories should be tested against the history of science and that's when a research program can be judged progressive.

In [4], Chalmers acknowledges that a corrected history poses problems for standard accounts of science and scientific method. However he agitates for a dynamic method otherwise science would be locked into a fixed position and make it dogmatic instead of adaptable. Unlike in [1-3], he takes a middle stand and argues that there are methods and standards in science, but they can vary from science to science and can, within a science, be changed, and changed for the better. Finally Chalmers proposes that there is a universal method seen from a common-sense perspective since most scientists agree on a number of basic criteria.

B. Partial anatomy of science

From the classical view, sciences can be vividly classified as shown in the table 1 below. At the pinnacle there is *Logic and Mathematics*. It is the central core of the science. To most of the philosophers of science, Logic and Mathematics is the abstract machinery (*hard core*) used to verify the validity of methods used in other sciences. Next, are the *natural sciences*, from which physics sits on the top and is regarded by most of the philosophers of science as the science. Most of the experiments and research programs discussed in the theory of science are based on physics. Below natural sciences, follow the social sciences and humanities that take the peripheral edge of sciences.

Table 1
Sciences, artifacts/objects and methods

Level	Science	Artifacts	Dominating method
1	Logic and Mathematics	Abstract artifact: propositions, numbers, etc.	Deduction
2	Natural Sciences	Natural artifact: Physical bodies, fields and interactions, living organisms, etc.	Hypothetico-deductive method
3	Social Sciences	Social artifact: human individuals, groups, society, etc.	Hypothetico-deductive method + hermeneutics
4	Humanities	Cultural artifact: human ideas, actions and relationships, language, etc.	Hermeneutics

From table 1, computing cuts across all discipline levels. Its interdisciplinary nature not only makes it hard for placement in the hierarchy of sciences, but also leaves questions on its methods. A detailed discussion is section 4 below.

III. A GENERAL VIEW AT SCIENTIFIC METHODS

The scientific community has an agreed approach or logical process for conducting research. It is through such a process that scientists discover or create new knowledge about the world in which we live. This logical process is referred to as the 'Scientific Method'. In [5] a scientific method is defined as “a body of techniques for investigating phenomena, acquiring new knowledge, or correcting and integrating previous knowledge. It is based on gathering observable, empirical and measurable evidence subject to specific principles of reasoning”. That is, scientists use it as conduit to study existing theories, produce new theories, design new tools (instruments, algorithms, etc.) all geared to solving real world problems.

In reality, there exists no such a specific scientific method that can be used from one discipline to another. In as much as there are variations in disciplines (natural sciences, physical sciences, social sciences, psychology, e.t.c), there are variations in procedures for conducting scientific research. Albeit the variations in the procedures there exist identifiable features in the methodologies used for each discipline that cut across. These cutting across

features qualify a method to be scientific from other types of methods. In any case, a scientific researcher starts from existing theoretical framework, formulate the problem, infer consequences, tests if it works as expected if not redefines ones premises and finally accepts the results.

We consider these steps as a logical way of doing science but not as a religious commandment. However, this does not imply that there are no such things as methods in science. The argument is that these steps must be repeatable in order to predict dependably any future results, but they are not beliefs. Even theories that encompass wider scope of inquiry may bind many hypotheses together in a coherent structure which might result into forming new hypotheses or grouping hypotheses into a unifying context.

Figure 3.1 from [6] depicts a general view of the logical structure of scientific method practice dating from the classical sciences view to the present. It is evident that the flowchart agrees with the classical views discussed in the above section.

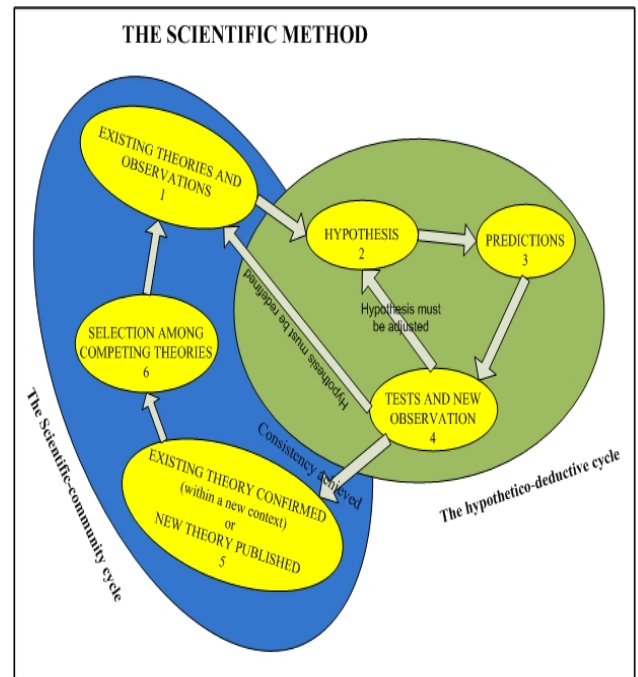


Figure 3.1: The Scientific method framework

In agreement with Chalmers in [4] as well as depicted in figure 3.1, there are universal frameworks within which science is done. Science is ever in state of permanent change and development, there are no closed ends of investigation. As the flowchart indicates, there are loops. This manifests that scientific results are provisional, i.e. results are subjected to continuous re-examination, challenge and self-correction. Scientific methods promote openness in the scientific community; it gives a leeway of

validating any scientific work other than accepting the result at glance. A theory is accepted based in the first place on the results obtained through logical reasoning, observation and /or experiments.

IV. COMPUTING DISCIPLINE AND ITS METHODS

A. *The Discipline of Computing*

Shackelford, et al. in [7] gives a broad view of the discipline of Computing. Denning, et al. [8] states three paradigms through which the discipline of computing is defined as *theory*, *abstraction* and *design*. The theory paradigm is rooted in mathematics. Abstraction is rooted in the experimental while the design paradigm is rooted in engineering. A cross sectional view at definitions of the three computing paradigms are so intricately intertwined that it is irrational to say that any one is fundamental. Instances of theory appear at every stage of abstraction and design, instances of design at every stage of theory and abstraction. Though the three paradigms are intricately intertwined, each is distinct from one another and represents a separate area of competence. The theory paradigm is concerned with the ability to describe and prove relationship among objects while the abstraction is concerned with how to use those relationships to make predictions that can be compared with the world. Design is concerned with the ability to implement specific instances of those relationships and use them to perform useful actions.

The scientific paradigm is the process of forming hypotheses and testing them through experiment, successful hypotheses become models that explain and predict phenomena in the real world. The logical process followed by the computing science in studying information processes suits well in scientific paradigm process. From a lexicographic perspective, the notable divergence in the definitions of the three computing paradigms is interpreted as a result of pure science and applied science. The pure science deals with the advancement of self knowledge, while the applied science deal with knowledge of demonstrable utility. Consequently, this qualifies that computing research follow the scientific paradigm and is exact science.

B. *The Methods in Computing Research*

In the section above, it has been cleared that computing is a science. Based on the ACM report [7] we note that the fields belong to level 1 and 2 as indicated in table 1 above. The most notable difference between computing and other sciences is the time factor at which computer artifacts under investigation or use change. Consequently the time

factor has an effect on the development and validity of the theories. For example, consider a research program to revisit the moon now. The computer artifacts to control a shuttle to the moon now would be totally different from those artifacts that were used to control Apollo 11 that landed the first man on moon in 1969. However, the time factor does not lead to falsification of the theory. It only leads to enrichment of the protective belt (in Lakatos words) and birth of new theories.

Below we investigate into the pertinent scientific method for computing. These are divided into three methodologies that align with distinct competences. Namely theoretical, experimental and simulation [6, 8, 9].

1) *Theoretical methodology in computing*: This area is concerned with the ability to describe and prove relationships among objects (artifacts) using logic (mathematics). It is categorized under level 1 of table 1, and follows the classical methodology of building theories as logical systems with stringent definitions of objects (axioms) and operations (rules) for validating or developing body of new knowledge (theories). Logic is concerned with criteria of validity of inferences and formal principles of reasoning. Since the days of Euclid, it has been a tool for rigorous mathematics and scientific argument. Its importance in computing can be summarized as; a) forms a basis of every computing programming language, b) investigation of upper-, lower- limits (resource bounds) during automatic calculation, and c) it ability to interpret strings of symbols as data and as programs.

That is, theory creates methodologies, logics and various semantics models to help design programs, to reason about programs, to prove their correctness, and to guide the design of new programming. Consequently theoretical computing seeks to understand both the limits of computation and the power of computational paradigm.

2) *Experimental methodology in computing*: Experimental computing is a discipline that studies phenomena that are solely the product of human creation. Among these are computational processes, algorithms, or mechanisms that manipulate or transform information [6, 9-11]. Unlike in traditional classic sciences where the object of inquiry is energy or matter, here it is information. Because of the complexity involved in understating the nature of information processes on the basis of direct analysis from first principles, scientist must observe such phenomena, formulate explanations and theories and test them empirically. That is, Experimental computer science refers to the creation of, or the experimentation with or on, computational artifacts [10]. However some of the challenges still facing this methodology are the lack of quantitative methods to measure the human factor (productivity, quality of artifacts made by humans, efficiency in operations, etc.). Even though some areas of

software engineering like the Human-Computer Interactions are striving to include the human factor in their models, proper metrics to measure such factors are not yet in place.

3) *Computer simulation methodology*: This is a third methodology in computing is a blend of itself (computing), applied mathematics and other science disciplines. It has come up as a way of complementing the already established methodologies (theoretical and experimental) that root from the classical scientific methods.

Modeling coupled with simulation has become an indispensable approach to tackle problems of great complexity. This has enabled scientist to investigate regimes that are beyond current experimental capabilities and to study phenomena that cannot be replicated in laboratories. Good example can be seen in current studies of Internet problems. The Internet as big as it is, cannot be replicated in laboratories. Simulation has become a de facto methodology for Internet problem studies.

Like any other scientific method, computer simulation is guided by formal procedures that lead the methodology in a continual interaction between theory (in the form of hypothesis and objective) as well as experimental results. Computer models are incorporated into hypothesis formulation, and are used in simulation studies to test ideas before they are tried experimentally. An iterative feedback between these tests and current ideas allows for a preliminary refinement of hypotheses and development of more intelligent investigations. In context, this methodology takes an advantage of abstraction to enable scientist to study the required phenomena based on models other than building physical ones, consequently costing less resources and time to generate new knowledge.

V. DISCUSSION OF SURVEY RESULTS

A. The Nature of the Survey and the Methodology used

The overall objective of the survey was to investigate the methods in use in computing research programs. It was conducted through a web based questioner. The data was collected from a select group of researchers known in the field of computing by graduate students who participated in the Theory of Science and Scientific Method course at Mid Sweden University in Fall 2007. The select group composed of 600 researchers that spanned over European, American, African and Asia - India universities and research institutions. No statistical method for sampling was used in selecting the questionees. A request was sent in an e-mail with a URL link of a web based questioner to the names in the select group. Out of the 600 contacted researchers, a total of 445 researchers from 90 different research institutions and universities responded positively

with fully filled questioners. Their data is the basis of the discussion in this paper. Table II below gives the distribution of the respondents' education background and research experience in field of computing.

Table II
Respondents' Education Background and Research Experience

No. of respondents	Highest Qualification	No. Years since attainment of highest qualification	Main Activity
82	PhD	≥ 10	Teaching, Research
54	PhD	5 – 9	Teaching, Research
67	PhD	1 – 4	Teaching, Research
114	Masters Degree - but all are PhD Candidates	1 – 6	Study, Teaching, Research
128	Masters Degree	1 - 5	Research, Systems Development

The data used in the overall investigation was categorized into three blocks as follows:

a) The respondent's area of specialty and experience in conducting research. This block classified the data on specialties based on the IEEE computing society/ACM – Computing curricula 2005 [7], while experience was considered in terms of researching years as indicated in table II above.

b) Global view of methods in use in research programs. Major investigation focused mainly on the government of methodological choices, data generation and capture methods for research programs, researcher's orientation/inclination (induction, deduction, or both) in using scientific method in research, and the research process - the level of adherence to the classical circle (i. start from existing theoretical framework, ii. formulate the problem, iii. infer consequences iv. test if it works as expected if not redefine your premises, and v. accept the result) in conducting scientific research.

c) Respondent's opinion on the methods used by their counterparts/colleagues in their particular specialties. The items under investigation were like those in b) above, except the focus was at individual research's specialty level.

B. Macro Level Analysis of Methods in Use

Though there are five broad subfields of computing as per IEEE/ACM [7], the survey showed that the researchers

in the field of computing do not stem or restrict to the IEEE/ACM subfields. Figure 5.1 below shows the respondents' distribution by specialty. Computer Science marked the highest number of respondents with 45.4%, while the lowest being Computer Engineering with 4.5%. However the survey revealed the sixth subfield hereby named as "None of the above". The "None of the above" respondents classified themselves as physicists, mathematicians, biologist, etc. though their research products/results are classified as computing artifacts.

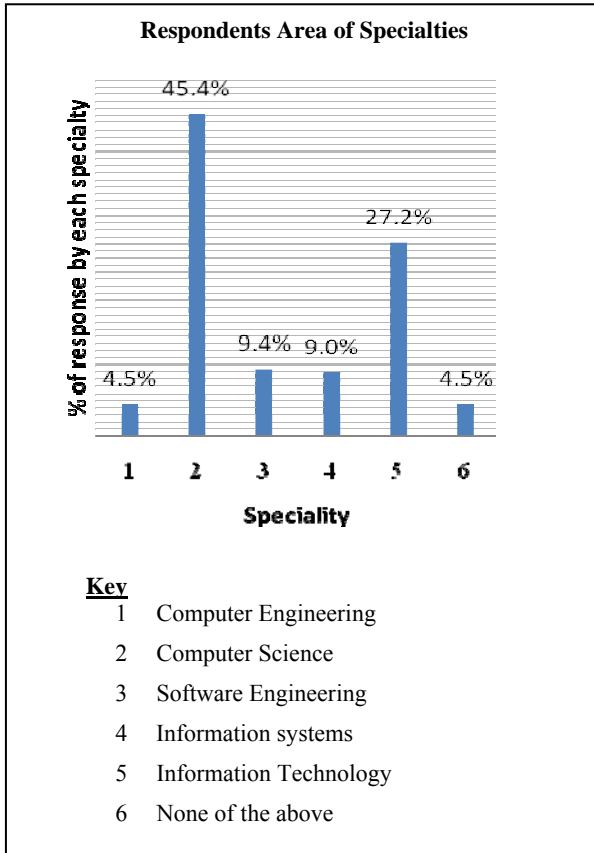


Figure 5.1: Respondents Area of Specialties

The occurrence of the "None of the above" category in the survey results is a clear manifest that computing cuts across all discipline levels. As noted in table 1 above, its interdisciplinary nature makes it had for placement in the hierarchy of sciences, and also identification of methods in use.

On government of methodological choices; 64% of the total respondents acknowledged that the market forces had a great influence on methodological choices. Although the extent to which market forces influencing the methodological choices was not deeply investigated in this study, the survey indicated that 92% of the 64% researchers that acknowledged the market forces' influence on methodological choices, reported of conducting research

programs in partnership with the industry. It was also noted that the findings of their research programs are the direct inputs of the industry. Consequently, since the industry objective is to meet the market demands, it implies that the choice of methods to us in such programs have to fulfill the industries' objectives.

On distinct methods in use; the feedback obtained from survey indicated a 59.1% usage of combined methodologies as the major method in use even though there are distinct specific methodological areas in computing as indicated in section IV.B above. The theoretical and experimental methodology each separate usage was 18.2%.

The overall use was high as indicated in figure 5.2 below.

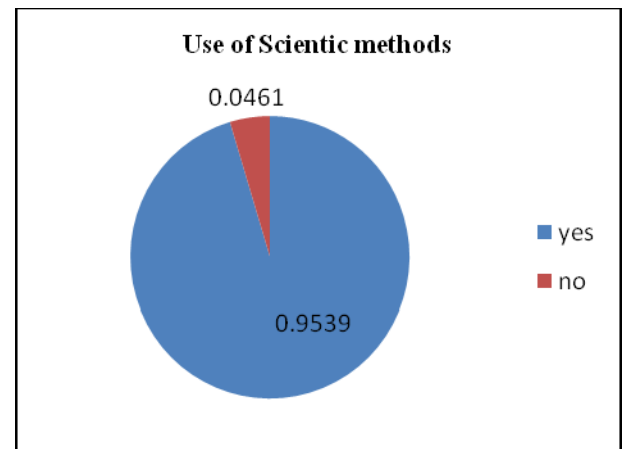


Figure 5.2: Use of scientific methods in computing research

Albeit the acceptance of the usage of scientific methods by the respondents, we noted strong indications that practicing researchers do not differentiate (or understand clearly the difference) between experimental and simulation methodologies. Others argue that the methods are the same, while others acknowledged the use of experimental method as distinct methodology in their research endeavors (even though are minority). But empirically [8] they are two distinct methods. We therefore conclude that some researchers do not have a thorough understating of the distinction between the two classical methods. This might be because of their background training or the level (in seniority) at which they conduct research.

Another strong point noted in the survey is on how data is collected and interpreted during the researchers in the field of computer science. The respondents showed strong use of experiment (both simulation and observations) as the method of data collection. Other methods seemed to be minor in data collection. While on

data interpretation, respondents acknowledged the use of mixed methods (mixed in this context are induction and deduction – through logic). Figure 5.3 below shows the respondents' level on data collection methods.

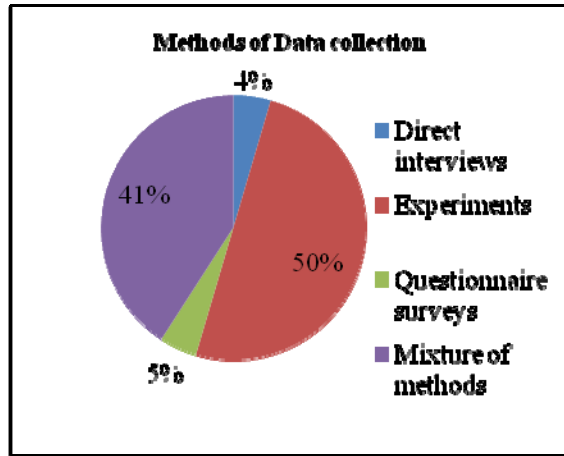


Figure 5.3: Methods of Data collection in computer science

75% of the respondents acknowledged the conformity of logical processes in computer science research programs to the classical logical processes of conduction scientific research programs. This showed that computer scientist also follow the classical processes and face all challenges of sciences face as indicated in figure 3.1 above. It reported that most of them state their hypothesis in term of goals, i.e. not implicit setting hypothesis, but setting a goal to give better results in performance or in solving a real world problem.

However this requires more investigation of what type of research and how scientific that research is for the 25% of respondents how seemed not to follow the classical view of conducting scientific research. Surprising enough, we noted an outlier data which indicates a never use of hypothesis in any program of research ever conducted.

C. Methods in Use Analysis at Specialty level

In our survey the fields of specialization (or professionalism in computing) where classified as per ACM/IEEE curriculum classification [7]. We noted that the response at specialization level was so poor. The picture portrayed from the data analysis represents individual respondent's views but not the entire profession/field's view.

However one point noted from the one of the respondents concerning experimental and simulation methodologies is worth discussion. A respondent commented that the distinction between experimental and simulation methodologies is not obvious, because every experimental work necessarily includes some kind of modeling fitting (which in essence leads to simulation) and every simulation work includes some kind of parameter fitting (in essence experimental).

We note the respondent's concern and argument. But in section IV.B above we noted that simulation is the youngest methodology that has mainly come up as a way of complementing the already established methodologies (theoretical and experimental), and that modeling coupled with simulation scientists are now able to tackle problems of great complexity. Therefore for any phenomenon of interest to be studied the first step is abstraction. That is, a model that takes account of relevant features of a phenomenon must be constructed. Generally not only in computing, but modeling is a process that always occurs in science. Theory, experiment and simulation are all about (more or less detailed) models of phenomena. Therefore, to accomplish any complicated problem simulation has to be brought in context but that does not mean it's not different from experimental methodology.

VI. CONCLUSION

In respect to classification, computing is a science whose object of inquiry is information. Understating the nature of information processes on the basis of direct analysis from first principles is very complex. Hence, scientists have to undergo through the process of observing the phenomena, formulating explanations and theories and conducting empirical tests. This process has lead classification of scientific methods for computer science into three distinct methodologies as theoretical, experimental and simulation. The dominating method for theoretical is deductive while experimental and simulation suit best hypothetico-deductive.

From the survey, respondents' view of practice is more geared to industry demands and their inquiries are driven by three characteristics of proof of performance, concept and existence. The consequence of such tendencies is that computing artifacts have resulted into a versatile venture. Their performance, concepts and existence change at click if a minute handle, which is a manifest of being more coupled to technology.

We call for a more comprehensive study on the subject since the findings in this paper are based on a representative sample group.

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