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"Computing" and "computational science" are broad terms that encompass multiple disciplines and undergraduate programs. It is useful to consider a range of computing-related disciplines; indeed, this Program Study Group uses the international term "computing" rather than the specific term "computer science" in its title to reflect this diversity.

At the undergraduate level, Computing Curricula 2005: The Overview Report [1] (citations may be found in the companion Supplemental Report), by the Association for Computing Machinery (ACM) and the Computer Society of the Institute for Electronics and Electronics Engineers (IEEE-CS) with the Association for Information Systems (AIS), provide separate curricular recommendations for each of five major programs in computing:

- *Computer engineering* focuses on hardware and the physical connectivity of equipment.

- *Computer science* "spans a wide range, from its theoretical and algorithmic foundations to cutting-edge developments" and includes software development and "effective ways to solve computing problems." [1, pp. 13-14]

- *Information systems* focuses "on integrating information technology and businesses processes to meet the information needs of businesses and other enterprises". [1, p. 14]

- *Information technology* refers "to undergraduate degree programs that prepare students to meet the computer technology needs of business,

- *Computational science and big data*. The ACM/IEEE-CS Computing Science Curricula 2013, Strawman Draft (February 2012) describes computational science as "the application of computer science to solve problems across a range of disciplines" [5, p. 47]. These disciplines are predominantly those in the natural sciences, but applications are increasingly in other areas.

- *Connections among statistics, machine learning, and databases* are of considerable and growing importance. A term in current use is “big data”; it denotes an emerging, interdisciplinary field that seeks to provide insights and analysis of the huge data sets that are collected in a wide range of application areas.

Mathematics interacts with each of these disciplines through a wide range of courses, interdisciplinary programs, majors, and minors. The connections between mathematics and these allied disciplines are not uniform; they depend substantially on the specific program. The examination of these connections entails considerations along at least two complementary dimensions. First, mathematics embraces at least three general perspectives: continuous mathematics, discrete mathematics, and statistics. Second, computing and computational science involve the various disciplines already described.

To clarify relationships between mathematics programs and programs involving computing and computational science, the next three sections of this Summary Report are organized according to traditional mathematical perspectives. In contrast, the structure of the associated Supplemental Report hig401.( )v/eseReport9Report9Rep

Computing has eroded the sharp distinction between continuous and discrete mathematics. Continuous quantities are often represented in discrete form. Important algorithms for solving, optimization, and probability use discrete steps in continuous settings. Examples are Markov Chain Monte Carlo methods for constructing probability distributions, multivariate integration in high dimensions, as well as solvers and optimizers. The computationally savvy student needs to understand connections between the continuous and discrete.

For computational science, it is important to have a solid grasp of concepts, such as equilibrium and stability, rather than algebraic techniques, such as integrating factors. The concept of function is central, as are operations such as differentiation, integration, solving, and optimization. Students need to understand a variety of representations of functions, not just algebraic formulas.

“Discrete mathematics” is a broad label for a variety of mathematical topics that share a focus on values or structures that cannot change smoothly and continuously. Common examples include logic, combinatorics, set theory, number theory, and graph theory. Many undergraduate mathematics programs include a different disciplines teaching their own flavor. In math departments, the introductory course often emphasizes applied probability and features simple, one-variable descriptions (e.g, mean, proportion, standard deviation) and classical tests (e.g., the t-test) using an algebra- and formula-based approach.

This organization of statistics does not serve computational students well. Computational science students, like other science students, need to be able to read the scientific literature. Nowadays, this calls for an understanding of the statistics of multiple variables. [14]

The algebra and probability derivations on which typical statistics courses are based

In the following table, C indicates conceptual mastery required, P practical mastery, and M modest practical understanding.

Expectation	C, P	C, P	M	P	C, P	C	C, P
Independence	C, P	C, P	M	P	C, P		