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Committee for Computing Education in Community Colleges

Bloom's for Computing

Enhancing Bloom's Revised Taxonomy with Verbs for Computing Disciplines

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Committee for Computing Education in Community Colleges (CCECC)

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Enhancing Bloom's Revised Taxonomy with Verbs for Computing Disciplines

Adeleye Bamkole, Passaic County Community College, NJ

Markus Geissler, Ph.D., Cosumnes River College, CA

Koudjo Koumadi, Ph.D., Prince George’s Community College, MD

Christian Servin, Ph.D., El Paso Community College, TX

Cara Tang, Ph.D., Portland Community College, OR *

Cindy S. Tucker, Bluegrass Community and Technical College, KY

* Task Force Chair

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Introduction

The ACM Committee for Computing Education in Community Colleges (CCECC) has long been using Bloom's Revised Taxonomy in composing learning outcomes and competencies for curricular guidance published for associate degree programs. The six levels in the taxonomy represent the varying levels of cognitive depth a student is expected to demonstrate. The CCECC learning outcomes have been carefully crafted using verbs from standard lists associated with each of the six levels. Through this experience, curriculum project members have often struggled with finding the right verb from the verb list to best express the desired learning outcome. A common case in which this struggle occurs concerns technical tasks for which a technical verb would be appropriate but is not available on the verb list. This repeated experience, across projects and across task force members, provided the initial motivation for taking on the project of suggesting computing-specific verbs to supplement the standard lists. Positive response from the community to the first draft of this report offered feedback that this is something the community is interested in and provided further motivation. The verbs found in this report are not limited to technical computing verbs, but are more generally verbs that could be useful for learning outcomes and competencies in computing programs and curricular guidance.

The *Bloom's for Computing* project began in July of 2020, with the task force scouring a number of different sources, including [1, 3, 9, 18, 19, 20], to produce an initial candidate list of verbs. A first draft of about 90 potential new verbs was disseminated in March - April of 2021 via a poster at SIGCSE 2021 and sent out on various mailing lists. A survey was used to gather feedback on the verbs, with 46 responses. This feedback was incorporated into the next draft which contained 77 proposed verbs and was disseminated in February - April of 2022. A survey gathered further feedback, with 28 responses, which were incorporated to mold the final report found in this document. This report presents 56 enhanced verbs for use along with typical Bloom's verbs. If this number seems large, it may be a reflection of changes in language, and especially the influence of computing disciplines and technology on the English language.

The target audience for this report is anyone who drafts competencies or learning outcomes for computing disciplines - whether programs, courses, individual modules, or curriculum guideline reports; whether two-year, four-year, graduate, or K-12 level; whether educators, instructional designers, or program coordinators.

Bloom's Revised Taxonomy

Assessment at Educational Institutions

Institutions must ensure an ongoing and effective process for assessing student learning. In particular, computing courses and programs of study must incorporate clearly defined, measurable student outcomes, demonstrating that student achievement at the course level promotes the successful attainment of program goals. Competencies and learning outcomes indicate a student's ability to do something successfully or efficiently and may also be used to measure achievement of objectives within a curricular module or unit.

This relationship is commonly demonstrated when:

- For each program of study, a collection of program outcomes is identified;
- For each course in the program, a collection of student learning outcomes is identified;
- For each course, topics of study and learning activities are selected and designed to support the course student outcomes;
- Each course student outcome supports one or more program outcomes; and
- Each program outcome is supported by one or more course outcomes.

Effective assessment provides valuable feedback to faculty and academic leaders for continuous improvement of pedagogy, course content, and program outcomes to better prepare students for future studies and careers. In addition, effective assessment fosters articulation between institutions, promotes student transfer, documents employment readiness, and facilitates job placement. Accreditation requirements, performance-based funding, and public demands for accountability also make effective educational assessment a necessity.

Bloom's Cognitive Domain

The foundational *Taxonomy of Educational Objectives: A Classification of Educational Goals* was established in 1956 by Dr. Benjamin Bloom, an educational psychologist, and is often referred to as Bloom's Taxonomy [7]. This classification divided educational objectives into three learning domains: Cognitive (knowledge), Affective (attitude), and Psychomotor (skills). In 2000, Lorin Anderson and David Krathwohl updated Bloom's seminal framework to create Bloom's Revised Taxonomy, focusing on the Cognitive and Affective Domains [3].

In computing curricula, the Cognitive domain is often used to assess student mastery of learning outcomes. There are six levels in the taxonomy for the Cognitive domain, progressing from the lowest order processes to the highest:

- *Remembering* - Retrieving, recalling, or recognizing information from memory. Students can recall or remember information. Note: This process is the most basic thinking skill.
- *Understanding* - Constructing meaning or explaining material from written, spoken or graphic sources. Students can explain ideas or concepts.
- *Applying* - Using learned materials or implementing materials in new situations. Students can use/apply information in a new way.
- *Analyzing* - Breaking material or concepts into parts, determining how the parts relate or interrelate to one another or to an overall structure or purpose. Students can distinguish between different parts.
- *Evaluating* - Assessing, making judgments and drawing conclusions from ideas, information, or data. Students can justify a stand or decision.
- *Creating* - Putting elements together or reorganizing them into a new way, form or product. Students can create a new product. Note: This process is the most difficult mental function.

In the framework of Bloom's Revised Taxonomy learners need not start at the lowest taxonomic level and work up; rather, the learning process can be initiated at any point, and the lower taxonomic levels will be subsumed within the learning scaffold. To wit:

- Before we can understand a concept, we have to remember it;
- Before we can apply the concept, we must understand it;
- Before we analyze it, we must be able to apply it;
- Before we can evaluate its impact, we must have analyzed it; and
- Before we can create, we must have remembered, understood, applied, analyzed, and evaluated.

When using Bloom's Revised Taxonomy in crafting competencies and learning outcomes, lists of verbs associated with each level in the taxonomy are often used. These verb lists may vary slightly depending on the source, but many of the same verbs are commonly found at particular levels, such as Define at the Remembering level, Describe at the Understanding level, and so on. Table 1 presents one such verb list, this one being the standard in use by the ACM CCECC (see ccecc.acm.org/assessment/blooms).

Limitations of Bloom's Revised Taxonomy

While it provides a useful framework which applies to many disciplines, Bloom's Revised Taxonomy is not without limitations. The linear arrangement into six levels adds simplicity and thus makes the framework more usable, but one of its major criticisms is that some verbs could be applied at several cognitive levels, and this can lead to the design of learning outcomes or competencies which may not accurately indicate the cognitive level. Concerns also exist with the hierarchical organization of Bloom's Revised Taxonomy which may inaccurately indicate the complexity and depth of a learning outcome for which the most fitting verb is not associated with the appropriate level of cognition. And as the English language evolves, the meaning and usage of some verbs will change and may eventually require a revision of the Taxonomy.

In addition, those who create learning outcomes are increasingly looking to include elements from the Affective Domain, which "includes the manner in which we deal with things emotionally, such as feelings, values, appreciation, enthusiasms, motivations, and attitudes" [10]. For this reason, the Cognitive Domain of Bloom's Taxonomy may no longer suffice to serve, as it does for many curriculum committees, as the sole source of verbs for defining learning outcomes or competencies which are increasingly expected to allow for the assessment of dispositions as well as skills.

Furthermore, and despite that "the relationship between fact learning and higher order learning is often speculated, but empirically unknown" [4], many educators have recently interpreted Bloom's taxonomies in such a way that the mastery of "lower order" tasks must precede efforts to engage students in "higher order" tasks [8]. Bloom and his collaborators did not intend to imply this connection, but the structure in which they chose to present both their original and revised taxonomies has led many to this conclusion.

Task force members evaluated several other learning taxonomies, including Niemierko's ABC taxonomy of learning objectives [16] as described in Fuller, et al [12], Bespalko's taxonomy [5] as described in Fuller, et al [12], Biggs & Collis' Structure of the Observed Learning Outcome (SOLO) taxonomy [6], and Simpson's Psychomotor Domain [17]. However, these taxonomies lack sufficient congruence with modern computing terminology, which renders them less than optimal for computing faculty who are looking to create meaningful learning outcomes.

Table 1: Bloom's Verbs

Assessment Verbs by Bloom's Level

Lower Order Thinking Skills → Higher Order Thinking Skills

Remembering	Understanding	Applying	Analyzing	Evaluating	Creating
Define	Classify	Apply	Analyze	Appraise	Assemble
Duplicate	Convert	Calculate	Attribute	Argue	Construct
Find	Demonstrate	Carry out	Categorize	Assess	Create
Identify	Describe	Edit	Compare	Choose	Design
Label	Differentiate	Diagram	Contrast	Critique	Develop
List	Discuss	Execute	Decompose	Debate	Devise
Locate	Exemplify	Illustrate	Deconstruct	Defend	Formulate
Memorize	Explain	Implement	Deduce	Estimate	Hypothesize
Name	Infer	Investigate	Discriminate	Evaluate	Invent
Recall	Interpret	Manipulate	Distinguish	Judge	Make
Recognize	Paraphrase	Modify	Examine	Justify	Plan
Retrieve	Report	Operate	Integrate	Support	
Select	Summarize	Perform	Organize	Test	
State	Translate	Produce	Outline	Value	
		Solve	Structure	Verify	
		Use			
		Write			

To address some of the limitations of Bloom's for computing disciplines, Fuller et al. proposed a new taxonomy for use in computer science education which is a two-dimensional adaptation of Bloom's cognitive levels. The Interpreting dimension includes Remember, Understand, Analyze, and Evaluate. The Producing dimension includes (none), Apply, and Create. Activities represented by the typical verbs as well as computing verbs fall somewhere in the two-dimensional matrix. For example, the verb "recognize" is in the cell representing Remember and (none); the verb "refactor" is in the cell representing Evaluate and Create [12]. This innovative work, however, has not been widely adopted, and the task force chose to build on the widely-used structure of Bloom's Revised Taxonomy in this project.

Bloom's Verbs for Computing

Enhanced Verbs

Table 2 lists 56 verbs, at the cognitive levels shown, to be offered as an enhancement for computing disciplines to the standard verb list presented earlier.

Table 2: Enhanced Verbs

Remembering	Understanding	Applying	Analyzing	Evaluating	Creating
Enumerate Reference	Annotate Comment	Backup Build Code Compile Compute Configure Connect Decrypt Deploy Document Encrypt Graph Install Iterate Map Measure Provision Randomize Recover Restore Schedule Store Train Virtualize	Articulate Automate Contextualize Correlate Detect Generalize Model Monitor Predict Simulate Trace Translate Update	Adapt Administer Debug Decide Optimize Prioritize Prove Validate	Collaborate Compose Generate Program Script Secure Visualize

As one may note in reviewing the list above, it includes verbs that can be used for technical computing tasks (such as Code, Compile, Encrypt, Debug, Script), verbs that can be used for dispositional or soft skills (such as Articulate, Collaborate), as well as verbs for more general use (such as Measure, Translate, Decide). All of these verbs can be used to write learning outcomes and competencies that students in computing programs may be expected to achieve. Not surprisingly, the Applying cognitive level has the greatest number of verbs as many tasks in computing disciplines fall into this category.

Verb Explanations and Sample Learning Outcomes

When considering how a verb might be used in a competency or learning outcome, it is helpful to see examples. Review the tables below to see at least two examples for each verb to demonstrate how they might be used in a curriculum framework for a computing discipline. The verbs' usage should not be seen as being limited to the meanings expressed in these examples. As mentioned earlier, a particular verb could represent varying levels of cognitive depth, but the usage of each verb is intended to represent the cognitive depth of the Bloom's level in which it has been placed. In addition to the sample competencies and learning outcomes there is a brief explanation or rationale for the inclusion of each verb.

The tables below include, for each level of Bloom's, the list of enhanced verbs at that level, with an explanation for how each might be useful, and numbered sample learning outcomes for each verb.

Table 3: Remembering

Verb	***Explanation* and Sample Learning Outcomes**
Enumerate	*Similar to List in non-computing uses, and also has computing uses* 1. Enumerate the essential steps of the cybersecurity kill-chain process. 2. Enumerate the steps in the software development lifecycle (SDLC). 3. Enumerate the values of a collection in a data collection set.
Reference	*Adds a skill not included directly in the original Bloom's list* 1. Reference multiple NIST Special Publications in a cyber-risk analysis report. 2. Reference sources of borrowed codes as comments within a computer program.

Table 4: Understanding

Verb	***Explanation* and Sample Learning Outcomes**
Annotate	*Clearly annotating diagrams is required in computing tasks such as designing system and network flows* 1. Annotate an attack graph in the context of cybersecurity threat modeling. 2. Annotate a network diagram with names of the components.
Comment	*Commenting codes is a recommended practice* 1. Comment a given segment of a program or script. 2. Comment on a network design diagram.

Table 5: Applying

Verb	***Explanation*** **and Sample Learning Outcomes**
Backup	*Common computing task, especially in system administration and data security* 1. Backup multiple local or remote files and folders to a backup volume. 2. Backup marked data to a remote location using an automation script.
Build	*Commonly used in many computing areas, such as operating systems, IT, systems programming* 1. Build a machine learning model to detect network intrusions. 2. Build a working multi-router network using an automation script.
Code	*Required task in many aspects of computing, including building virtualized infrastructure* 1. Code a Python program from a given flowchart. 2. Code a cloud infrastructure orchestration using a scripting language.
Compile	*Common software development task, especially when coding in compiled languages such as C and C++* 1. Compile a program using the command line interface. 2. Compile a low level code for a specific operating system.
Compute	*Common task in computer science* 1. Compute conditional probabilities. 2. Compute message digests of saved files using various hashing algorithms.
Configure	*Common real-word task in system administration, networking, and cybersecurity* 1. Configure a UNIX-based operating system in order to harden it. 2. Configure a firewall to block or allow traffic based on IP addresses and port numbers.
Connect	*Required in networking, system configuration, and other information exchange environments* 1. Connect two remote sites using a tunneling technology. 2. Connect multiple branch routers to a headquarters router using virtual private networks. 3. Connect a workstation to a router to configure the router.
Decrypt	*Commonly required for information security objectives* 1. Decrypt a ciphertext using the appropriate cryptographic technique. 2. Decrypt a received email using a private key.
Deploy	*Common computing task* 1. Deploy a machine learning pipeline to achieve a successful algorithm. 2. Deploy multiple instances of a template virtual machine.

Verb	*Explanation* and Sample Learning Outcomes
Document	*Common computing task, includes source code documentation as well as system documentation* 1. Document the processes of an information system at multiple levels of detail. 2. Document a project for version control by keeping track of the software environment.
Encrypt	*Common computing task with emphasis in cybersecurity* 1. Encrypt files or folders using an appropriate system utility. 2. Encrypt computer users' data using an RSA encryption tool.
Graph	*Verb used in data structures and algorithms as well as data science and analytics* 1. Graph a data set using an appropriate chart type. 2. Graph a combinatorial problem using depth-first and breadth-first search.
Install	*Common computing task, especially in system administration* 1. Install a given software patch. 2. Install a docker engine in a given operating system. 3. Install a hardware firewall device on a network.
Iterate	*Common computing task in programming languages and many computing areas* 1. Iterate through a list in a given programming language. 2. Iterate a machine learning algorithm and indicate the number of times the algorithm's parameters are updated.
Map	*Common computing verb in IT and programming* 1. Map an entity relationship diagram to tables in a relational database. 2. Map a shared folder by assigning a drive letter.
Measure	*Common computing verb in IT and computer science* 1. Measure performance of algorithms on dimensions of time and space. 2. Measure the round trip time (RTT) between two servers.
Provision	*Common task in cloud computing and DevOps areas* 1. Provision resources in a virtual environment. 2. Provision cloud equipment with software or services to users/clients.
Randomize	*Verb used in algorithms, data sciences, and cybersecurity areas* 1. Randomize numbers in an algorithm to simulate random behavior. 2. Randomize an encryption algorithm by using a degree of randomness in its logic or within a procedure. 3. Randomize strong initial passwords for new user accounts on a system.
Recover	*Common computing task* 1. Recover files from an operating system as a forensics application. 2. Recover data based upon a given search term, from an imaged system.

Verb	***Explanation*** **and Sample Learning Outcomes**
Restore	*Common computing task* 1. Restore files and folders from a backup volume to a local or remote drive/folder. 2. Restore code for a program or application from an earlier version of the software using version control.
Schedule	*Computing task with multiple applications, especially in IT* 1. Schedule backups to meet data management policies in an organization. 2. Schedule steps in a cybersecurity assessment for a given scenario.
Store	*Common computing task* 1. Store data securely in the cloud. 2. Store data and software securely at an offsite location.
Train	*Used in machine learning and data science, as well as other computing areas* 1. Train a prediction model by using online data to improve its accuracy. 2. Train a machine learning model with stored data. 3. Train users to spot phishing emails.
Virtualize	*Action verb in lieu of "use virtualization"* 1. Virtualize components/resources at the server and client levels for a given scenario. 2. Virtualize an application deployment for a given scenario.

Table 6: Analyzing

Verb	***Explanation*** **and Sample Learning Outcomes**
Articulate	*Allows for a deeper cognitive level when compared to other Bloom's synonyms such as Explain and Describe* 1. Articulate a testing strategy for a given function. 2. Articulate legal issues, authorities, and processes related to digital evidence.
Automate	*Common task in computing disciplines, requiring prior analysis* 1. Automate a user function, such as generating an electronic invoice or generating an error message/alert. 2. Automate an initial incident response for a security breach for a given scenario.
Contextualize	*Allows a deeper insight into computing concepts by studying the context which surround given scenarios* 1. Contextualize security vulnerabilities for a given piece of software within a given scenario. 2. Contextualize social and professional aspects of computing with respect to ethical codes of conduct.

Verb	*Explanation* and Sample Learning Outcomes
Correlate	*Analyzes the relationship between multiple computing concepts and the impact they have on one another* 1. Correlate the cost of computing resources with improved security. 2. Correlate privacy, security and trust for a given scenario.
Detect	*Common task, especially in cybersecurity* 1. Detect a potential vulnerability in a given source code. 2. Detect an instance of false sharing.
Generalize	*Allows a deeper cognitive level when compared to other Bloom's synonyms such as Summarize and Explain* 1. Generalize the specific tasks completed by a point-of-sale system. 2. Generalize security vulnerabilities in various data structures.
Model	*Common computing task and uses an action verb in lieu of "use modeling"* 1. Model a business problem mathematically or with an algorithm. 2. Model a real-world problem using graphs and trees, such as representing a network topology or the organization of a hierarchical file system.
Monitor	*Common task for anomalies deterrence and uncovering errors in many computing disciplines* 1. Monitor network traffic for security vulnerabilities. 2. Monitor input controls into an end-point to prevent invalid or erroneous data from entering the system. 3. Monitor the identity of users or groups who request access to sensitive resources.
Predict	*Common analysis and decision making task applicable to many computing and technology projects* 1. Predict the output of an algorithm after it has been trained on a historical dataset and applied to new data. 2. Predict the cost and benefits trade-off that may be associated with a system recovery plan. 3. Predict for an organization what management, organization, and technology factors are responsible for the difficulties in building electronic medical records systems.
Simulate	*Common verb applicable to planning, analysis and testing in computing disciplines* 1. Simulate a disaster recovery response. 2. Simulate the role of personnel in a given business group working environment. 3. Simulate mobile device usage during web application testing and prototyping.
Trace	*Common task applicable to many computing, system administration, networking, and cybersecurity tasks* 1. Trace a variable's value as it changes throughout a code module. 2. Trace a list attached or linked to personnel who are not allowed access to any part or function of the system. 3. Trace an activity to detect the condition that creates a deadlock.

Verb	***Explanation*** **and Sample Learning Outcomes**
Translate	*Common task in programming, information systems, networking and security* 1. Translate a business problem into an artificial intelligence and data science solution. 2. Translate a given system design specification into software program code. 3. Translate written communication to effective oral communication.
Update	*Common computing task* 1. Update a data-based model for a given scenario. 2. Update the features of a website to match the information requirements of an organization or user needs. 3. Update software to include new features.

Table 7: Evaluating

Verb	***Explanation*** **and Sample Learning Outcomes**
Adapt	*Common computing task in computing disciplines* 1. Adapt a given network defense strategy to a new network configuration. 2. Adapt a script feature to suit a specific function or task. 3. Adapt software to changing industry standards.
Administer	*Common task in information systems, networking and security* 1. Administer virtual machines serving a wide user base. 2. Administer an information system for a local business such as a doctor's office, grocery store or a fast-food restaurant. 3. Administer a web server. 4. Administer tools and techniques to design and implement a technical solution for a system process.
Debug	*Verb used in troubleshooting and error checking; common task across computing disciplines* 1. Debug a given segment of code. 2. Debug a common printing problem. 3. Debug an entity relationship diagram of a database for anomalies. 4. Debug software by utilizing appropriate techniques.
Decide	*Common verb used in evaluation of best practices in any computing areas* 1. Decide between several appropriate methods for securing a wireless network. 2. Decide on the appropriate resolution to a help desk request. 3. Decide the best practices for safety when working with networks and end points. 4. Decide on the best data structure for a particular scenario.
Optimize	*Common computing goal* 1. Optimize a segment of code by using fast functions. 2. Optimize network flow by configuring Access Control Lists on firewall ports.

Verb	***Explanation*** **and Sample Learning Outcomes**
Prioritize	*Multiple possible uses in computing as well as soft skills* 1. Prioritize a search algorithm using a data structure such as binary heaps. 2. Prioritize network traffic by enabling quality of service functionality. 3. Prioritize daily and weekly tasks to accomplish critical work and meet deadlines.
Prove	*Useful in mathematical and forensic environments* 1. Prove elementary theorems on probability. 2. Prove the presence of a security vulnerability in endpoint devices.
Validate	*Useful skill in several computing disciplines* 1. Validate software security within a given test plan. 2. Validate a server cluster using an appropriate system utility.

Table 8: Creating

Verb	***Explanation*** **and Sample Learning Outcomes**
Collaborate	*Useful soft skill when interacting with computing colleagues and end users* 1. Collaborate with team members to produce a given computer artifact. 2. Collaborate with fellow teammates and users to conduct a needs analysis for a point-of-sale system.
Compose	*Useful integrative skill; more flexible than Program* 1. Compose a new class using principles of object-orientation to support a new feature in a software system. 2. Compose shell scripts that run without direct interaction.
Generate	*Useful skill for developing content from existing data or tools* 1. Generate meaningful reports from various data sets. 2. Generate revealing statistics from spreadsheet data by using appropriate Microsoft Excel functions.
Program	*Common computing task* 1. Program a routine that starts code segments on multiple devices when a certain condition is met. 2. Program an automated routine that will pause the smart sprinkler controller when local rainfall exceeds a given threshold.
Script	*Common computing task; more specific than Program* 1. Script an algorithm to perform form verification using pattern matching and regular expressions. 2. Script commands to instantiate virtual resources.
Secure	*Common computing task across all computing disciplines* 1. Secure a transaction between a browser and a web server. 2. Secure a local area network against denial-of-service attacks.

Verb	*Explanation* and Sample Learning Outcomes
Visualize	*Useful integrative skill with certain computing tools* 1. Visualize a data model using well-known libraries for data analysis. 2. Visualize patterns of access to a system to track an intruder.

Reformulating Learning Outcomes Using Enhanced Verbs

To further demonstrate how the enhanced verbs could be used, we have reformulated some competencies and learning outcomes (LOs) from the ACM curriculum guidelines listed below.

- CCDS2021 - Computing Competencies for Undergraduate Data Science Curricula [2]
- CSEC2017 - Curriculum Guidelines for Post-Secondary Degree Programs in Cybersecurity [15]
- IT2017 - Curriculum Guidelines for Baccalaureate Degree Programs in Information Technology [20]
- CS2013 - Curriculum Guidelines for Undergraduate Programs in Computer Science [14]

The examples in Table 9 show how a formulation can be improved, made more direct, or targeted at a more appropriate cognitive level.

Table 9: Competency Improvements

ACM Guideline	Existing Competency / LO	Possible Competency / LO with New Verb
CCDS2021	Demonstrate contexts in which Bayesian networks can be useful (e.g., diagnostic problems).	**Contextualize** effective Bayesian networks (e.g., diagnostic problems). *Analyzing*
CCDS2021	Justify the need for probabilistic reasoning.	**Simulate** a data model using probabilistic reasoning. *Analyzing*
CCDS2021	State what a Markov Decision Process is, giving a small or medium sized example.	**Trace** a Markov Decision Process with a small or medium sized example. *Analyzing*
CSEC2017	Demonstrate the ability to implement approaches for detection and mitigation of social engineering attacks.	**Detect** social engineering attacks. *Analyzing* Note: Mitigation could be incorporated separately.
CSEC2017	Explain the various authentication techniques and their strengths and weaknesses.	**Monitor** various authentication techniques using methods appropriate to each. *Analyzing*

ACM Guideline	Existing Competency / LO	Possible Competency / LO with New Verb
CSEC2017	Describe a buffer overflow and why it is a potential security problem.	**Trace** a buffer overflow security problem in a given program. *Analyzing*
IT2017	Implement virtualization for applications, desktops, servers, and network platforms.	**Virtualize** applications, desktops, servers, and network platforms for a given scenario. *Applying*
IT2017	Illustrate the goals of secure coding, and show how to use these goals as guideposts in dealing with preventing buffer overflow, wrapper code, and securing method access.	**Secure** a given program with respect to buffer overflow, wrapper code, and method access. *Creating*
IT2017	Perform simulations and describe security and performance issues related to wireless networks.	**Simulate** various security and performance issues related to wireless networks. *Analyzing*
CS2013	Explain what is meant by “best”, “expected”, and “worst” case behavior of an algorithm.	**Measure** “best”, “expected”, and “worst” case behavior of a given algorithm. *Applying*
CS2013	Give examples that illustrate time-space trade-offs of algorithms.	**Compute** time and space costs for two different algorithms that perform the same task, demonstrating the time-space tradeoff. *Applying*

Some of the competencies or learning outcomes defined in previously published ACM curriculum guidelines, including A Competency Model for Undergraduate Programs in Information Systems (IS2020) [13] and Computing Curricula 2020 (CC2020) [1], already use enhanced verbs, serving as further evidence of the usefulness of those verbs. Examples include the following:

- In IT2017: **Collaborate** in the creation of an interesting and relevant app (mobile or web) based on user experience design, functionality, and security analysis and build the app’s program using standard libraries, unit testing tools, and collaborative version control.
- In IS2020: **Secure** a database.
- In IS2020: **Articulate** the nature and potential of Big Data.
- In CC2020: **Predict** the behavior of systems under random events using knowledge of probability and expectation and inform users of its potential behavior.
- In CC2020: **Document** industry trends, innovations, and new technologies and produce a report to influence a targeted workspace.
- In CC2020: **Monitor** application performance indicators and implement corrective actions.
- In CC2020: **Deploy** an IT application that satisfies user needs in the context of processes that integrate analysis, design, implementation, and operations.

Original Plus Enhanced Verbs

Table 10 presents the original list of verbs plus the enhanced verbs. A table of all verbs on a single page is provided at the end of this document for easy printing, or as a separate document available at the CCECC website (ccecc.acm.org/assessment/blooms-for-computing).

*Table 10: Original verbs with **enhanced verbs in bold***

Remembering	Understanding	Applying		Analyzing	Evaluating	Creating
Define	**Annotate**	Apply	Investigate	Analyze	**Adapt**	Assemble
Duplicate	Classify	**Backup**	**Iterate**	**Articulate**	**Administer**	**Collaborate**
Enumerate	**Comment**	**Build**	Manipulate	Attribute	Appraise	**Compose**
Find	Convert	Calculate	**Map**	**Automate**	Argue	Construct
Identify	Demonstrate	Carry out	**Measure**	Categorize	Assess	Create
Label	Describe	**Code**	Modify	Compare	Choose	Design
List	Differentiate	**Compile**	Operate	**Contextualize**	Critique	Develop
Locate	Discuss	**Compute**	Perform	Contrast	Debate	Devise
Memorize	Exemplify	**Configure**	Produce	**Correlate**	**Debug**	Formulate
Name	Explain	**Connect**	**Provision**	Decompose	**Decide**	**Generate**
Recall	Infer	**Decrypt**	**Randomize**	Deconstruct	Defend	Hypothesize
Recognize	Interpret	**Deploy**	**Recover**	Deduce	Estimate	Invent
Reference	Paraphrase	Diagram	**Restore**	**Detect**	Evaluate	Make
Retrieve	Report	**Document**	**Schedule**	Discriminate	Judge	Plan
Select	Summarize	Edit	Solve	Distinguish	Justify	**Program**
State	Translate	**Encrypt**	**Store**	Examine	**Optimize**	**Script**
		Execute	**Train**	**Generalize**	**Prioritize**	**Secure**
		Graph	Use	Integrate	**Prove**	**Visualize**
		Illustrate	**Virtualize**	**Model**	Support	
		Implement	Write	**Monitor**	Test	
		Install		Organize	**Validate**	
				Outline	Value	
				Predict	Verify	
				Simulate		
				Structure		
				Trace		
				Translate		
				Update		

Guidance for Writing Learning Outcomes and Competencies

Bloom's verbs are commonly used to write program, course, and lesson competencies and student learning outcomes. For our purposes, competencies follow the definition presented in Modelling Competencies for Computing Education beyond 2020: A Research Based Approach to Defining Competencies in the Computing Disciplines [11]: "Competency integrates knowledge, skills, and dispositions and is context-situated." Knowledge ("know-that") refers to "mastery of core concepts and content knowledge." Skills ("know-how") are "qualities that people develop and learn over time with practice and through interactions with others." Dispositions ("know-why" and "know-yourself") include "attitudinal, behavioral, and socio-emotional qualities of how disposed people are to apply knowledge and skills to solve problems." Context is the setting in which competencies manifest, the "authentic situations related to problems/issues and aspects of work." [11]

The recent ACM/IEEE-CS report *Computing Curricula 2020 (CC2020): Paradigms for Global Computing Education* describes dispositions as "the opportunity to express institutional and programmatic values expected in the workplace" and "ascribing a disposition to a competency indicates a clear commitment to self-reflection and examination that distinctly distinguishes a competency from a learning outcome" [1]. Table 11 is presented in that report as prospective elements of dispositions:

Table 11: Dispositions

Element	**Elaboration**	**Element**	**Elaboration**
Adaptable	Flexible, agile, adjust in response to change	Professional	Professionalism, discretion, ethical, astute
Collaborative	Team player, willing to work with others	Purpose-driven	Goal driven, achieve goals, business acumen
Inventive	Exploratory, look beyond simple solutions	Responsible	Use judgment, discretion, act appropriately
Meticulous	Attentive to detail, thoroughness, accurate	Responsive	Respectful, react quickly and positively
Passionate	Conviction, strong commitment, compelling	Self-directed	Self-motivated, determination, independent
Proactive	With initiative, self-starter, independent		

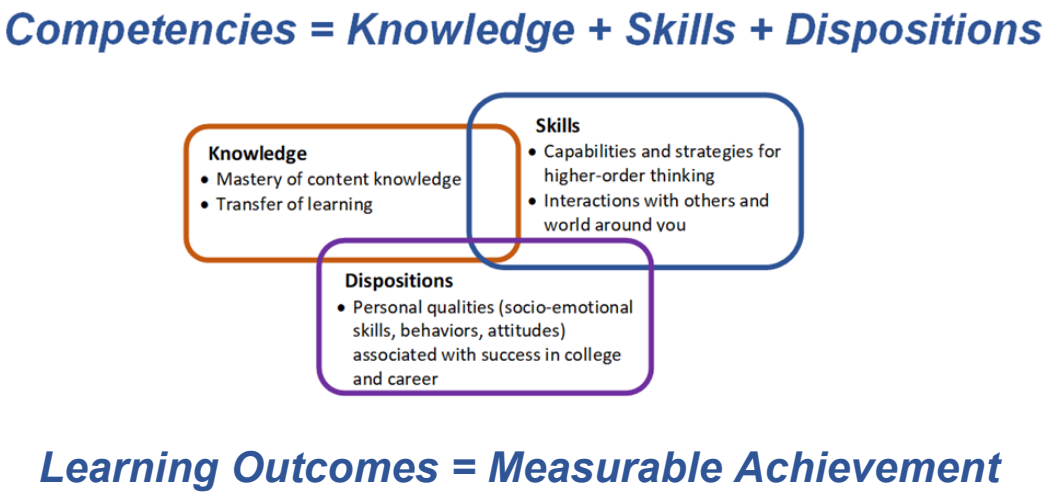
The following are sample competencies and associated dispositions from CC2020 updated with enhanced Bloom's verbs:

- Articulate the robustness, expandability, and throughput of several networking topologies used within a cloud enterprise. (Dispositions: self-directed, purpose-driven, responsible)
- Monitor the design of a computer system for a manufacturer using appropriate tools, design digital circuits including the basic building blocks of Boolean algebra, computer numbering systems, data encoding, combinatorial and sequential elements. (Dispositions: self-directed, meticulous, inventive)
- Document system requirements by applying a known requirements elicitation technique in work sessions with stakeholders, using facilitative skills, as a contributing member of a requirements team. (Dispositions: purpose-driven, responsible, collaborative)

Learning outcomes focus on achievement, what students can do in some measurable way, rather than what students know. They are used to develop lesson and course outcomes. Student learning outcomes are more detailed than competencies and are often accompanied with outcome metrics, such as rubrics. It is not unusual to define multiple learning outcomes for a given competency. Learning outcomes contribute to achievement of course competencies which in turn contribute to program competencies.

In review, competencies are written as general statements that describe desired knowledge, skills, and dispositions of students within an academic program or course while learning outcomes express, in a measurable detailed manner, what a student can do at the end of the lesson, course, or program (see Figure 2).

Figure 1: Competencies and Learning Outcomes



Using the six (6) cognitive levels in Bloom's Revised Taxonomy, each of the proposed enhanced computing verbs has an assigned cognitive level. Table 12 lists a few examples.

Table 12: Bloom's Cognitive Levels

Bloom's Level	***Sample Computing Verbs***
Remembering	Enumerate, Reference
Understanding	Annotate, Comment
Applying	Code, Encrypt, Decrypt
Analyzing	Detect, Trace, Translate
Evaluating	Administer, Debug, Optimize
Creating	Script, Collaborate, Visualize

A variety of computing concepts are taught and learned at a lower cognitive level initially and progress to a higher cognitive level over time. The enhanced computing verbs provide select "families" of verbs to facilitate writing competencies and learning outcomes which illustrate student achievement and growth from lower to higher cognitive levels. For example,

1. **Code**, **Script**, and **Program** are similar concepts. For the purposes of this document we use **Code** at the Applying level whereas **Script** and **Program** are used at the Creating level. Students may begin their learning at an Applying level with tasks such as translating detailed specifications into code, but ultimately demonstrate what they know and can do at the Creating level with tasks such as implementing a solution to an abstract problem. Learning outcomes can be written to demonstrate this progress.
2. **Design**, **Develop** and **Build** are also similar. **Design** and **Develop** are verbs from Bloom's Revised Taxonomy at the Creating level. **Build** is a proposed new computing verb at the Applying Level. Again, this provides a way for students to provide a computing solution to a problem but at different cognitive levels.
3. **Convert, Translate,** and **Transform** can be used to illustrate changes to computing artifacts at three different cognitive levels (Understanding, Analyzing, and Evaluating respectively).

At present, ACM recognizes seven (7) computing disciplines [1]:

1. Computer Engineering
2. Computer Science
3. Cybersecurity
4. Information Systems
5. Information Technology
6. Software Engineering
7. Data Science

Each of these disciplines has its own unique field of study and computing vocabulary. As such, the new computing verbs to enhance Bloom's Revised Taxonomy are inclusive of all computing disciplines. Some verbs may be applicable for all disciplines while others may only apply to one or two disciplines. For example,

- **Encrypt** and **Decrypt** work well for Cybersecurity, Information Technology, and Computer Science.
- **Configure**, **Install**, and **Schedule** are common tasks in Information Technology.
- **Experiment**, **Update**, and **Collaborate** are used across all computing disciplines.

When using these enhanced verbs to develop or revise a computing curriculum or course, it is important to remember each verb implies a specific cognitive level of learning. When writing competencies and learning outcomes, authors should carefully select a verb at the appropriate cognitive level for the intended outcome. Use one verb per competency or learning outcome and compose the statement in a measurable, clear, and concise manner. It is recommended that this enhanced list of computing verbs and the associated list of national and regional endorsements be shared with local curriculum committees and other groups who are reviewing curriculum proposals.

Endorsements

The list of organizations that have endorsed this report is available at our website (ccecc.acm.org/assessment/blooms-for-computing) and continues to grow. If you represent a group that would be interested in endorsing this report, please use the contact information provided on the website.

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Bloom's for Computing

Remembering	Understanding	Applying		Analyzing	Evaluating	Creating
Define	**Annotate**	Apply	Investigate	Analyze	**Adapt**	Assemble
Duplicate	Classify	**Backup**	**Iterate**	**Articulate**	**Administer**	**Collaborate**
Enumerate	**Comment**	**Build**	Manipulate	Attribute	Appraise	**Compose**
Find	Convert	Calculate	**Map**	**Automate**	Argue	Construct
Identify	Demonstrate	Carry out	Measure	Categorize	Assess	Create
Label	Describe	**Code**	Modify	Compare	Choose	Design
List	Differentiate	**Compile**	Operate	**Contextualize**	Critique	Develop
Locate	Discuss	**Compute**	Perform	Contrast	Debate	Devise
Memorize	Exemplify	**Configure**	Produce	**Correlate**	**Debug**	Formulate
Name	Explain	**Connect**	Provision	Decompose	**Decide**	**Generate**
Recall	Infer	**Decrypt**	Randomize	Deconstruct	Defend	Hypothesize
Recognize	Interpret	**Deploy**	Recover	Deduce	Estimate	Invent
Reference	Paraphrase	Diagram	Restore	**Detect**	Evaluate	Make
Retrieve	Report	**Document**	Schedule	Discriminate	Judge	Plan
Select	Summarize	Edit	Solve	Distinguish	Justify	**Program**
State	Translate	**Encrypt**	Store	Examine	**Optimize**	**Script**
		Execute	Train	**Generalize**	**Prioritize**	**Secure**
		Graph	Use	Integrate	**Prove**	**Visualize**
		Illustrate	Virtualize	**Model**	Support	
		Implement	Write	**Monitor**	Test	
		Install		Organize	**Validate**	
				Outline	Value	
				Predict	Verify	
				Simulate		
				Structure		
				Trace		
				Translate		
				Update		

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