TECHNOLOGY OBSERVATION PROTOCOL

TOP Science

Protocol 3.0 Observer Reference Guide

Introduction to *TOP-Science*

The Technology Observation Protocol for Science, or *TOP-Science*, is a validated research tool that can be used to describe the quality of technology implementation in high school science classrooms. With funds from the National Science Foundation, our team from the Education Development Center and University of Maryland Center for Environmental Science developed this tool because few protocols directly measure quality and most only consider science content, or technology use, or specific instructional practices; they do not consider all of these together. *TOP-Science* is unique in that it defines quality as the use of technology to support instruction that is student-centered, contextualized and targets science and engineering practices (as described in the Next Generation Science Standards). This definition of quality is based on the Classroom Technology Implementation Framework (CTIF; Parker, Stylinski, Bonney, Schillaci, & McAuliffe, 2015), which we constructed from reviewing technology-intense teacher training projects (part of the NSF ITEST program) and from extensive review of recent literature of technology integration and student-centered pedagogical practices in science classrooms. Thus, the *TOP-Science* aligns with theories of effective student learning and high-quality instruction.

The *TOP-Science* can be used to document the implementation of technology in science classrooms, and the quality of how technology applications are integrated with instructional practices. As such, its purpose is as a data gathering tool for researchers and program evaluators to characterize technology use in high school science classrooms. It can be used to address broad, field-based, applied research questions, or evaluate specific technology program effectiveness. Aspects of the protocol can be adapted to suit their needs. For example, questions may be added to the pre- and post-observation teacher questionnaires that address specific technology-related variables of interest (e.g., whether technology used in the classroom is student-supplied or school-supplied).

Additionally, although not designed for this purpose, it may be used by teachers to engage in formative reflection on their use of technology in their teaching practices. However, it is very important to note that *TOP-Science* **should not be used to assess teachers, is not appropriate for high-stakes evaluation purposes, nor should it be used to measure student outcomes**.

> ***Note:*** **TOP-Science** ***focuses only on digital technology which use processors to process data in a digital format, specifically software applications and the contextual settings in which specific technology applications are most commonly used.***

Digital technology includes machines and equipment that utilize processors which store or transmit information in digital format (Pullen, Baguley, & Marsden, 2009). Conway, Harris, Smith, Brackett, and Hayes (2016) define digital technology as "any information used on a computer or disseminated on a computer… [which] can enhance the level of creativity and distribution of information" (p. 206). A computer is any electronic device that accepts and processes data, usually in binary form (Computer, n.d.). While this is most commonly assumed to encompass desktop and laptop computers, it also includes such devices as mainframes, tablets, and smartphones. Consistent with these definitions of digital technology, examples may include computer programs and software, websites, databases, and digital media. See Appendix A for more discussion on technology definitions.

Technology and Science and Engineering Practices

Technology applications, both those designed specifically for instruction and those closely aligned with similar science workplace applications, have the potential to help teachers align their instruction to meet NGSS' emphasis on real-world science and engineering pursuits. Under these new classroom conditions, researchers and practitioners are challenged to understand how teachers can best use digital tools to improve instructional practice to support student learning in the context of NGSS. For example, computer simulations can help scaffold students' understanding and learning during inquiry-based activities (De Jong, 2006), and might also facilitate STEM learning by aligning with real-world practices, such as with project-based learning (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000).

The SEPs are one of the three dimensions of the NGSS and consist of eight practices:

1. Asking questions (for science) and defining problems (for engineering);
2. Developing and using models;
3. Planning and carrying out investigations;
4. Analyzing and interpreting data;
5. Using mathematics and computational thinking;
6. Constructing explanations (for science) and designing solutions (for engineering);
7. Engaging in argument from evidence; and
8. Obtaining, evaluating, and communicating information.

These practices are interwoven with the 113 grade 9-12 standards of the NGSS, and it would be challenging to envision a protocol that could consider all possible combinations between them and technology. While a subset of standards could be a focus (e.g., earth science), this could significantly limit the usefulness of an observation protocol. Thus, our protocol reflects on technology integration with the eight SEPs without regard to specific conceptual references -- that is, it is conceptually agnostic and can be applied within any high school science or engineering course.

Technology and Student-Centered Teaching

Student-centered teaching involves instructional practices that allow students to have a more self-directed experience with their learning. Maddux and Johnson (2006) note that technology implementation strategies are most successful when they are more student-centered and move away from teacher-directed instruction. For this protocol, we have adapted a definition from the Nellie Mae Education Foundation (NMEF), and define student-centered teaching as encompassing personalized instruction, student autonomy or ownership of the learning process, and competency-based instruction (NMEF & Parthenon-EY, 2015; Reif, Shultz, & Ellis, 2016). Nellie Mae's definition includes a fourth component of student-centered teaching, that learning can happen anytime, anywhere; however, this component addresses learning that happens outside the classroom, which is beyond the scope of this protocol.

Personalized instruction occurs when students' individual skills, interests, and developmental needs are taken into account for instruction. Students have autonomy over their own learning when they have frequent opportunities to take ownership of their learning process and have a degree of choice. Competency-based teaching is defined as teaching that progresses based on students' mastery of skills and knowledge, rather than being dictated by how much time has been spent on an activity or topic.

Integrating technology in a student-centered classroom can occur in a variety of ways. Technology applications may allow students to learn in a student-centered way that would not otherwise be possible without the technology. For example, access to information may allow student learning to be individualized; access to multiple modalities of learning might allow for personalization, or a learning management system might facilitate student-teacher and student-student collaboration or portfolios that promote competency-based learning. Technology might also support student-centered teaching such that students may have autonomy over what kind of technology to use for an activity, or when technology use might be appropriate. Having the conditions under which technology is used in the students' control could be a "potential enabler" of student-centered learning (NMEF & Parthenon-EY, 2015, p. 6).

Technology and Contextualized Teaching

The use of technology in classrooms enables teachers to make learning more relevant to the world in which students live (Brophy, Klein, Portsmore, & Rogers, 2008; Hayden, Ouyang, Scinski, Olszewski, & Bielefeldt, 2011; Miller, Chang, Wang, Beier, & Klisch, 2011). Since the 1990s, there has been an emphasis on trying to make science more relevant to students; prior to this, the emphasis had been on making the general population more "science literate" in an increasingly technological society (Fensham, 2004). The proponents of making science content more relevant to students are generally those who argue that such instructional practices lead to student-centered learning and increase student motivation for learning science (Moeller & Reitzes, 2011; Ravitz, Wong, & Becker, 2000; Stearns, Morgan, Capraro, & Capraro, 2012).

One of the more common ways to increase the relevance of science to students includes making connections between the content and the real world in which students live. This idea of increasing relevance is also sometimes referred to as authentic learning (Lombardi, 2007; Reeves, Herrington, & Oliver, 2002). Grounding lessons in the local geographic context, making connections to youth culture, or matching classroom tasks and activities with those of professionals in practice are all ways in which learning can be made more relevant or authentic to students. Technology can be used to support and facilitate this type of authentic learning via such tools as web resources and search engines, online discussions or emails, online simulated environments, digital photography or voice recorders (Herrington & Kervin, 2007).

Technology Observation Protocol (TOP)-Science

TOP-Science consists of four parts:

1. **Pre-Observation Teacher Questions**. These questions are sent to teachers via email to be completed before the observation, and serve to prepare the observer for what kind of class will be observed, what kinds of technology might be used, and the instructional practices the teacher might use during the class. Responses to these questions help frame the observation around the intentionality of instructional practices that might be observed.

2. **Classroom Observation Form**. This form contains the majority of information obtained by this protocol. It consists of two parts: *Observation Information* documents information about the observation (e.g., date of observation, name of observer, course name, number of students); and the *Activity Sheets*, used in 10-minute increments, allow observers to record classroom observations using the CTIF framework using both coding mechanisms and qualitative descriptions.

3. **Post-Observation Teacher Questions**. Teachers are asked these questions after the observation period is complete (either in person or via telephone/e-mail). They allow the observer to follow

up with the teacher with any questions they have about the observed class, identify any unexpected challenges with respect to technology use that came up during the observation, and clarify the intentionality of the observed teaching practices. The responses help inform the Post-Observation Summary.

4. **Post-Observation Code Summary Ratings**. After completing the post-observation teacher questions, the observer tabulates summary ratings to provide an overview of what was observed. The process of determining the summary ratings includes developing short qualitative descriptions of the classroom context (obtained from the Pre-Observation and Post-Observation Teacher Questions, as well as from the observation itself), and aggregating and averaging the quantitative scores obtained from the Activity Sheets. These scores and descriptions can then be used to analyze the quality of technology integration in classroom teaching.

This reference guide provides descriptive text and examples to help observers complete all four parts of the protocol.

Part 1: Pre-Observation Teacher Questions

Purpose

The purpose of the pre-observation teacher questions is for the observer to get a sense of what they will be seeing in the classroom. The questionnaire will inform observers of the teacher's plan for technology integration. Overall plans for the class, as reported by the teacher, will give observers an idea of what Science and Engineering practices (SEPs) may be targeted during the lesson, the level of student-centeredness and contextualization that may be observed, technology tool applications that may be used, and the extent to which the current lesson builds on previous lessons or work.

Tip: Observers should email the questions to the teacher approximately one week before they plan to conduct their classroom observation, so the responses may be received prior to the observation.

Questions

Each question posed to the teachers is aligned with our framework and is designed to provide context to the observation and insight into the intentionality of the teacher. Users of this protocol may choose to add their own questions to this list, based on their own research interests and intentions.

Questions 1 and 2 request descriptive information in a format familiar to teachers, while Questions 3-8 provide the observer with information that helps place the class within the CTIF framework.

1. **What is the name of the course?**

   This question provides context for the type of content that might be observed, and at what level the course will be taught (e.g., Honors, College Prep).

2. **In what grade are the students?**

   This question provides context for the level at which the course might be taught. Is it a course for freshmen? Seniors? An elective available to all grades?

3. **What are the big ideas (e.g., content, skills, competencies) that students will understand from this lesson or unit?**

   This question can prepare observers for the content and structure of the lesson (e.g., lab experiment, research, assessment), and which (if any) Science and Engineering Practices (SEPs) may be seen during the observation. Answers to this question also help observers understand the kinds of goals that teachers have for students.

4. **Please provide a description of how you will use technology to support understanding these big ideas.**

   This question can prepare the observer for what kinds of technology applications will be observed, which (if any) SEPs may be seen, as well as the extent to which student-centered and *contextualized teaching practices may be employed. Answers to this question also help observers understand how teachers define technology for the lesson.*

5. **What specific technology hardware and software will you or your students be using (e.g., learning management systems, Vernier probes, excel, GPS/GIS)?**

   This question can also prepare the observer for what kinds of technology applications will be observed.

6. **If this lesson is part of a larger unit or project-based learning, briefly describe what you have done previously and what you plan to do later in terms of science content, science and engineering practices, and technology use.**

   This question provides background on how the observed lesson fits in with what students have been learning, and whether this may be part of a long-term project-based learning activity. The observer may also learn more about student-centered and contextualization intentions from the teacher. Because researchers rarely have an opportunity to observe more than one or two classrooms and teachers often design their instruction to cross multiple days or even weeks, this question helps observers understand teachers' broader instructional intentions.

7. **Why have you chosen to use technology with this lesson?**

   This question again aims at assessing what types of technology applications will be used in the observed lesson, as well as gaining insight into possible student-centered and contextualized teaching practices that may be observed.

8. **Please provide any materials you can before the class (e.g., attachments of handouts you will be using, weblinks), or provide the observer with the handouts when they get to class.**

   It is very helpful for observers to be able to look at materials before, during, and/or after the observation.

9. **Is there anything else we should know about the selected lesson/unit or your students?**

   Some teachers will use this opportunity to inform the observer about behavioral or structural issues in the classroom that may impact the observation.

Part 2: Classroom Observation Form

The Classroom Observation Form consists of two sections: 1) Observation Information and Classroom Setup, and 2) Activity Sheet. We provide an overview of what these sections include and how an observer should complete these sections.

Section 1: Observation Information

Section 1 asks for basic information about the class that will be observed. Most of this information will be provided by the teacher on the pre-observation Teacher Questionnaire, and the rest will be completed by the observer prior to or at the beginning of the observation period. It only needs to be completed once per class period.

Observation Information	
Observation date	
Observer name	
Teacher name	
Teacher code	
School name	
Course name	
Number of students	
Grade(s) of students	
Start/end of class period	

Section 2: Activity Sheet

Section 2 is where the majority of information during the classroom observation will be recorded. Each activity sheet is designed to record one 10-minute time period; therefore, observers will complete multiple sheets for each class period, depending on the length of the class period (e.g., six sheets for a 60-minute class). The purpose of this section is to provide a snapshot of what is occurring in a classroom during a given 10-minute increment. Although the specific activities and types of technology used are not included in the post-observation summary ratings, they are important pieces of contextual information that may help the observer later reflect on what was happening in the classroom during a given time period. Descriptions of each data field on the Activity Sheet are provided below.

Activity Description	**Teacher code:**	**Sheet No.**
Time period covered by this sheet (10 minute increments)	Time started: __________ Time finished: __________	
Activities Observed e.g., lecture, discussion, individual seatwork, hands-on activity, group work, assessment, test preparation, homework review		

Hardware Types Used e.g., desktop/laptop computers, mobile devices, smartboard, probes, graphing calculator		
Software or Applications Used e.g., Word, web browser		
Technology Application Types	☐ **INSTRUCTIONAL** ☐ **UBIQUITOUS** ☐ **STEM WORKPLACE**	**Detailed description**

Tip: Teacher code and Sheet No. are for researchers' use in data management. Observers can format this section ahead of time by adding in the anticipated number of activity sheets, and pre-populating the Teacher code on each form.

Time. Observers should note the approximate start and end time (in 10-minute increments) covered by that activity sheet. This can be completed ahead of time, if the observer knows what time the class starts. This is used for record-keeping purposes.

Activities Observed. Provide a brief description of the activity (e.g., discussion, watching video). The list of activities provided is not meant to be an exhaustive or comprehensive list of activities, but is merely a suggestion of possibilities of common activities that may occur in a classroom. The activities observed will contribute to the narrative description of the classroom in the post-observation documents. Because teachers may introduce prerequisite and relevant content or skills to students before bringing technology into the lesson, observers should record all classroom activities, even if technology is not being used.

Hardware Types Used. Record any technology *hardware* for the activity covered by the activity sheet. The list provided is not meant to be exhaustive or comprehensive; any technology hardware used should be noted.

Software or Applications Used. Record any technology *software* or applications used during the time period covered by the activity sheet. The list provided is not meant to be exhaustive or comprehensive; any software or technology application used should be noted. When asked about technology, some teachers think of hardware, and some teachers think of software; therefore, we allow for space to list both, even though the focus of this protocol is on how teachers use the software and technology applications.

Technology Application Types. Technology applications may be used in a variety of ways, therefore this section addresses the different categories of technology applications, based on where they are most commonly used. Please describe the technology application observed, and check off the technology application type in the right column.

Note: The setting in which a technology application is most commonly used will change over time. It is important to review these classifications with your observation team, to determine the most appropriate category for observed technology applications.

We define technology application types based on the setting in which a technology application (usually software) is most commonly used. As noted above, this designation may change over time. For example, Microsoft Excel was originally designed as a professional spreadsheet tool and was most commonly used only in workplace settings. It has since become more ubiquitous, and used in all settings including classroom, home, and workplace settings. Although an observer may see students using Excel in a way that mirrors how scientists might use the software (e.g., data analysis and graphing), it should still be coded as a ubiquitous technology type, since the more advanced use of Excel will be reflected in the SEP and SEPTech ratings (see below for descriptions of these codes).

TECHNOLOGY APPLICATION TYPES	
Technology application categories	Examples of technology applications observed in the appropriate category
Instructional: Technology applications most commonly used in classroom or educational settings	Assessing tools (e.g., clicker software, Gradebook), online course management (e.g., Blackboard, Schoology, PowerSchool, Google Classroom);
Ubiquitous: Technology applications most commonly used in all settings, whether classroom, social, or workplace settings	Word processing (e.g., Microsoft Word), social networking (e.g., Facebook, Twitter), presentation applications (e.g., PowerPoint, GoogleSlide), video (e.g., YouTube, QuickTime), data recording and analysis (Excel, GoogleSheet), Web browsers and search engines (e.g., Chrome, Firefox)
STEM Workplace: Technology applications most commonly used in STEM workplace	Computer modeling and simulations (e.g., Stella, Ecobeaker, PhET, gizmo), image data analysis (e.g., ImageJ), geographic information system (e.g., ArcGIS), mapping tools (e.g., Fieldscope), propeware for field data collection (e.g., Vernier or LoggerPro probes)

The second part of the Activity Sheet includes sections for recording codes, field notes and evidence aligned with the CTIF. Each category and coding scheme is described in greater detail below.

Activity Coding and Field Notes. There are three main categories that align with our framework: Science and Engineering practices (SEPs), student-centered teaching, and contextualized teaching. Each of these categories can be broken down into sub-categories, which correspond to the **category codes** and help the observer frame what they may observe into pieces that are more manageable. **Level codes** reflect the degree to which the particular category is observed in the classroom (i.e., no evidence, incidental, embedded). **Technology codes** indicate the extent to which technology is being integrated with that particular category (i.e., no technology used, minimally integrated, partially integrated, fully integrated). **Field notes and evidence** provide documentation and justification for the previously described codes.

When entering category codes, observers should check off either "No evidence" or at least one of the multiple sub-categories. More than one category code may be selected, but only one level code and one technology code may be selected. The level and technology codes should be selected based on what best reflects the entirety of the 10-minute period.

Tip: Notes made in the "Evidence" cells should be focused on providing support and justification for the code selections. Any additional documentation the observers feel is important to make about the classroom and/or lessons should be included in the "Field Notes" cells.

Activity Field Notes & Coding

Category	Level[a]	Tech Codes[b]	Field Notes & Evidence for Level, Tech & Category Codes
Science and Engineering Practices ☐ **1.** Asking questions & defining problems ☐ **2.** Developing & using models ☐ **3.** Planning & carrying out investigations ☐ **4.** Analyzing & interpreting data ☐ **5.** Using mathematics & computational thinking ☐ **6.** Constructing explanations & designing solutions ☐ **7.** Engaging in argument from evidence ☐ **8.** Obtaining, evaluating, & communicating information	○ N ○ I ○ E	○ NT ○ M ○ P ○ F ○ N/A	**Field Notes** **Evidence (will be transferred to Post-Observation Summary)**
Student Centered Teaching ☐ Autonomous ☐ Personalized ☐ Competency-based	○ N ○ I ○ E	○ NT ○ M ○ P ○ F ○ N/A	**Field Notes** **Evidence (will be transferred to Post-Observation Summary)**
Contextualized Teaching ☐ Youth Experience ☐ Science careers or work ☐ Local/geographic context	○ N ○ I ○ E	○ NT ○ M ○ P ○ F ○ N/A	**Field Notes** **Evidence (will be transferred to Post-Observation Summary)**

[a]**LEVEL CODES**: **N**o evidence • **I**ncidental • **E**mbedded
[b]**TECH CODES: N**o **T**ech • **M**inimally integrated • **P**artially integrated • **F**ully integrated • **N**ot **A**pplicable (if category code is N or None)

Science and Engineering Practices. This section examines the extent to which Science and Engineering Practices (SEPs), as defined by the National Resource Council's (2012) *Framework*, are present during the observed activity. Observers record the presence of each SEP (see Category Code section below) during the lesson, and make a note in the *Field Notes and Evidence* column about the activities and degree to which the SEP is used in the classroom.

Category Code. The table below summarizes each practice; observers should familiarize themselves with, and refer to this table as they determine the extent to which teachers may be focusing on these practices with their students. The category code is not part of the post-observation summary ratings, but serves as an important cue to what observers should be attending during the class period. Although we do not directly ask the teacher which SEPs they will be targeting, their answer to the pre-observation questions about the goals of the lesson and big picture ideas they hope students will learn should give an indication of the types of practices that may occur during the observation.

Tip: In this protocol, observers should indicate what the teacher does and how the teacher has set up the lesson and specific activities to encourage students' engagement with SEPs. The student role in the classroom should be noted in relation to the teacher's action, especially if the student role differs from the teacher's intention.

SCIENCE AND ENGINEERING PRACTICES	
Practice	**Summary and Examples**
Asking questions or defining problems	Teacher encourages students to: (1) ask questions about the natural or human-built world; (2) distinguish a scientific question; (3) formulate and refine questions that can be answered empirically in a science classroom and use them to design an inquiry or construct a pragmatic solution; (4) ask probing questions that seek to identify the premises of an argument, request further elaboration, refine a research question or engineering problem, or challenge the interpretation of a data set; (5) note features, patterns, or contradictions in observations and ask questions about them; (6) for engineering, ask questions about the need or desire to be met in order to define constraints and specifications for a solution.
	Example: Teacher presents an issue. Much is written about this issue (beyond the teacher's knowledge), so the teacher organizes students into groups focused on different aspects of the issue and students conduct web searches using various reputable sources to summarize current understanding of the issue. Groups share their background research and from this develop testable scientific questions on this issue.
Developing and using models	Teacher encourages students to: (1) construct drawings or diagrams as representations of events or systems; (2) represent or explain phenomena with multiple types of models; (3) discuss the limitation and precision of a model as the representation of a system, process, or design and suggest ways in which the model might be improved to better fit available evidence or better reflect a design's specifications. Refine a model in light of empirical evidence or criticism to improve its quality or explanatory power; (4) use (provided) computer simulations or simulations developed with simple simulation tools as a tool for understanding and investigating aspects of a system, particularly those not readily visible to the naked eye; (5) make and use a model to test a design, or aspects of a design, and to compare the effectiveness of different design solutions.
	Example: In a lesson about the food chain, students study the predator-prey mathematical model. They apply the model for the case of rabbits and foxes by using a computer simulation. After exploring different model parameters with the simulator, the students deduce that the predator-prey model can be applied to other resource-consumer applications, such as plant-herbivore, parasite-host, tumor cells (virus)-immune system, etc. They investigate a model and simulation with three variables (grass-rabbits-foxes) to understand extensions of models applied to larger systems.
Planning and carrying out investigations	Teacher encourages students to: (1) formulate a question that can be investigated within the scope of the classroom, school laboratory, or field with available resources and, when appropriate, frame a hypothesis (a possible explanation that predicts a particular and stable outcome) based on a model or theory; (2) decide what data are to be gathered, what tools are needed to do the gathering, and how measurements will be recorded; (3) decide how much data are needed to produce reliable measurements and consider any limitations on the precision of the data; (4) plan experimental or field research procedures, identifying relevant independent and dependent variables and, when appropriate, the need for controls; (5) consider possible confounding variables and ensure that the investigation design has controlled for them.
	Example: *Teacher has students select sampling sites in their school yard for a field investigation. Students have to identify impervious surfaces (e.g., parking lot, roofs) and pervious surfaces (lawns, natural areas) and pick two sites on each surface that they can easily access each week. Students use a mapping software and examine an aerial image of their schoolyard to help them pick two sites.*
Analyzing and interpreting data	Teacher encourages students to: (1) analyze data systematically, either to look for salient patterns or to test whether data are consistent with an initial hypothesis; (2) recognize when data are in conflict with expectations and consider what revisions to the initial model are needed; (3) use spreadsheets, databases, tables, charts, graphs, statistics, mathematics, and information and computer technology to collate, summarize and display data and to explore relationships between variables, especially those representing input and output; (4) evaluate the strength of a conclusion that can be inferred from any data set, using appropriate grade-level mathematical

	and statistical techniques; (5) recognize patterns in data that suggest relationships when investigating further. Distinguish between causal and correlational relationships; (6) collect data from physical models and analyze the performance of a design under a range of conditions.
	Example:Teacher has students record data from investigation and explore the relationships between variables. Teacher provides access to spreadsheet (on hard drive or in cloud). Students use the spreadsheet to record data and perform the necessary unit conversions. They display the data in a table form with proper headings. They assess the data in the table and select two data columns (variables) to explore. Using the spreadsheet graphing capability, students make a scatter plot of two data columns to check whether the pattern of the data reveal any relationships between the two variables.
Using mathematics and computational thinking	Teacher encourages students to: (1) recognize dimensional quantities and use appropriate units in scientific applications of mathematical formulas and graphs; (2) express relationships and quantities in appropriate mathematical or algorithmic forms for scientific modeling and investigations; (3) recognize that computer simulations are built on mathematical models that incorporate underlying assumptions about the phenomena or systems studied; (4) use simple test cases of mathematical expressions, computer programs, or simulations--that is, compare their outcomes with what is known about the real world--to see if they "make sense"; (5) use grade-level appropriate understandings of mathematics and statistics in analyzing data.
	Example:The teacher has the students do an experiment to study the behavior of a bouncing ball. Students use a video recorder to record the ball bouncing across the floor. They use a x-y grid as background for video so they can get the x, y location of the ball in the video frame. From watching the videos, students record the x,y, and t data points on a spreadsheet. They use the spreadsheet to make calculations and plot the data and compare the graphs with the mathematical model of the bouncing ball that the teacher has provided to them.
Constructing explanations and designing solutions	For science work, teacher encourages students to: (1) construct their own explanations of phenomena using their knowledge of accepted scientific theory and linking it to models and evidence; (2) use primary or secondary scientific evidence and models to support or refute an explanatory account of a phenomenon; (3) offer causal explanations appropriate to their level of scientific knowledge; (4) identify gaps or weaknesses in explanatory accounts (their own or those of others). For engineering work, teacher encourages students to: (1) solve design problems by appropriately applying their scientific knowledge; (2) undertake design projects, engaging in all steps of the design cycle and producing a plan that meets specific design criteria; (3) construct a device or implement a design solution; (4) evaluate and critique competing design solutions based on jointly-developed and agreed-on design criteria.
	Example: In the experiment to study the behavior of a bouncing ball, the teacher has students construct an explanation to account for the decreasing heights of the ball in successive bounces. Their explanations are supported by data, plots, and mathematical model from using technology. They provide a more complete, consistent, and persuasive explanations because the technology allows them to easily analyze the data, try different scenarios, and come up with a mathematical model.
Engaging in argument from evidence	Teacher encourages students to: (1) construct a scientific argument showing how data support a claim; (2) identify possible weaknesses in scientific arguments, appropriate to the students' level of knowledge, and discuss them using reasoning and evidence; (3) identify flaws in their own arguments and modify and improve them in response to criticism; (4) recognize that the major features of scientific arguments are claims, data, and reasons, and distinguish these elements in examples; (5) explain the nature of the controversy in the development of a given scientific idea, describe the debate that surrounded its inception, and indicate why one particular theory succeeded; (6) explain how claims to knowledge are judged by the scientific community today and articulate the merits and limitations of peer review and the need for independent replication of critical investigations; (7) read media reports of science or technology in a critical manner so as to identify their strengths and weaknesses.
	Example: In the experiment to study the behavior of bouncing balls, the teacher has student teams use different types of balls. After the teams have constructed their explanations, the teacher has them engage in discussions and arguments about why different types of balls bounced differently. Students use data and formulae that are in their spreadsheets. It is easy for them discuss their data and to try different model parameters to compare alternative models and/or explanations. For example, one team believes that another team has an incorrect mathematical model. Teams are able to use the spreadsheet to quickly try different parameters for their formulae, compare the revised model with the data and previous models.
Obtaining, evaluating and communicating information	Teacher encourages students to: (1) use words, tables, diagrams, and graphs (whether in hard copy or electronically), as well as mathematical expressions, to communicate their understanding or to ask questions about a system under study; (2) read scientific and engineering text, including tables, diagrams, and graphs, commensurate with their scientific knowledge and explain the key ideas being communicated; (3) recognize the major features of scientific and engineering writing and speaking and be able to produce written and illustrated text or oral presentations that communicate their own ideas and accomplishments; (4) engage in a

	critical reading of primary scientific literature (adapted for classroom use) or of media reports of science and discuss the validity and reliability of the data, hypotheses, and conclusions. Technology may be used throughout include for collaborations with off-site partners.
	Example: Teacher has students create and present a powerpoint of their review of scientific writing on impacts of climate change on spring budburst. They integrate their own text along with figures, tables, and graphics that they took from online sources. They place them in an appropriate order in the powerpoint slides and use powerpoint features to present the information to other students and answer questions.

Level. Observers should record the code I (Incidental SEPs), or E (Embedded SEPs) when observing teachers encouraging or facilitating students' engagement with any of the eight SEPs (see Category Code section above for definitions and examples). Evidence of **incidental** SEPs might include a low emphasis on engaging in the practice, or a temporally brief engagement with the SEP. For example, in the planning and carrying investigation example above, students spend couple of minutes of a ten-minute interval, forming teams consisting of their friends without factoring team members' potential contributions to content knowledge and experience with tools. Evidence of **embedded** SEPs might be exhibited by a high emphasis on or longer use of the SEP. For example, in the next two ten-minute intervals, teams plan their investigations by discussing which mapping software and soil database to use and set up a spreadsheet and assign tasks and schedules for each team member. An N code (no evidence of SEPs) would indicate the absence of evidence of SEP engagement during that 10-minute increment.

Technology Integration Code. Observers should record in the field notes and evidence column how technology was integrated with the use of SEPs. If technology is not used for a particular activity, but is related to or connected to a previous activity during which technology was used, this connection should be noted. Technology codes are based on the integration of technology tools with each other as well as that facilitate the tasks within the activity.

Observers should record the code M (Minimally integrated), P (Partially integrated), or F (Fully integrated) when observing technology use in the activity. Specific examples of each can be found below to help in determining the appropriate codes to use. For example, if almost the whole activity involves technology, but technology supports only the recall and reproduction level of cognitive processes, then the observer should record M (Minimally integrated). An N/A technology code should be used if no evidence of SEPs is observed.

- **No technology**: Students engage in SEP without using any digital technology, or digital technology is used but does not play a role in SEPs.
- **Minimally integrated**: The lesson could be done with or without technology. Technology supports simple 1-step procedures such as recall, identify, recognize, calculate, tabulate, measure (e.g., convert numbers in Excel or reproduce list with Word).
- **Partially integrated**: The technology enhances student engagement with SEPs and supports multi-step procedures such as summarize, identify patterns, sketch, estimated, show (e.g., record/display data in Excel or classify digital photos).
- **Fully integrated**: The technology transforms student engagement with SEPs by allowing students to accomplish tasks and develop understanding that they could not otherwise do. Technology supports critical thinking including reasoning, planning, and thinking of complex and abstract tasks such as making connections, developing arguments, citing evidence, assessing, revising, synthesizing, defining (e.g., using digital data to draw conclusions).

Science and engineering practices example using SEP 3 (Planning and carrying out investigations):	
No technology	Teacher sets up a chemistry lab for students to learn how changes in variables affect the timing of chemical reactions using baking soda and vinegar. Students hypothesize how and what changes will impact chemical reactions and then design and implement a study to test their hypothesis. Chemical reaction time is visually determined by when the bubbles stop forming, and measured using the classroom clock. *No tech: students observe changes in reaction time visually and use classroom clock to measure time.*
Minimally integrated	Teacher sets up a chemistry lab for students to learn how changes in variables affect the timing of chemical reactions using baking soda and vinegar. Students hypothesize how and what changes will impact chemical reactions and then design and implement a study to test their hypothesis. Chemical reaction time is visually determined when the bubbles stop bubbling, using a smartphone to record time more accurately. *Minimal: students observe changes in reaction time visually and use phones to provide more accurate time measurement.*
Partially integrated	Teacher sets up a chemistry lab for students to learn how changes in variables affect the timing of chemical reactions using baking soda and vinegar. Students hypothesize how and what changes will impact chemical reactions and then design and implement a study to test their hypothesis. Chemical reaction time is measured using a Vernier Probe to assess change in pressure in a test tube and document differences in reaction times. *Partial: students measure reaction time using Vernier probes, use phones to provide accurate time measurement, look only at 'faster/slower,' not at specific rates of change.*
Fully integrated	Teacher sets up a chemistry lab for students to learn how changes in variables affect the timing of chemical reactions using baking soda and vinegar. Students hypothesize how and what changes will impact chemical reactions and then design and implement a study to test their hypothesis. Chemical reaction time is measured using a Vernier Probe to assess change in pressure in a test tube. The probes are connected to computers that record the data into an excel file and allow students to graph rates of change by dependent variable (e.g., amount of baking soda, temperature of vinegar). *Full: Probes are connected to laptops, allowing digital data to be recorded and used to calculate rates of change.*

Student-Centered Teaching. We define student-centered teaching as including three components[1]: 1) instruction is personalized, 2) students have autonomy over their own learning, and 3) learning is competency-based (Lampert, 2015; NMEF & Parthenon-EY, 2015). Observers should take note of the extent to which teaching and learning in the classroom incorporates these components.

Category Code. For each of the three components of student-centered teaching, observers should consider whether the instruction they are observing falls into one of these categories when coding for level and technology integration.

- *Personalized instruction* is defined as teaching that takes students' individual skills, interests, and developmental needs into account.
- When students have *autonomy* over their own learning, they have frequent opportunities to take ownership of and have a degree of choice over their learning process, and may use formative assessments to monitor and reflect on their learning progress.
- *Competency-based teaching* is defined as teaching that progresses based on students' mastery of skills and knowledge, and is not necessarily dictated by how much time has been spent on an activity.

Level. Observers should record the code N (not student-centered), I (incidental student-centeredness), or E (embedded student-centeredness) when observing instances of personalized

[1] The cited research also addresses a fourth component of student-centered learning: learning can happen anywhere and anytime; however, since this component describes learning that happens outside of the classroom, which is outside the scope of this protocol, it is not included in this framework.

instruction, student autonomy, and competency-based teaching (see Category Code section above for definitions). Evidence of **incidental** student-centeredness might be the teacher controlling most of the technology in the classroom, whether it is by limiting what technology students may use, when or how it is used for a lesson. The teacher may provide a small degree of personalized instruction, student autonomy, or competency-based instruction, but it is limited. **Embedded** student-centeredness might be exhibited with most or all of the technology decisions (i.e., what, when, how) being made by students. There may be a high degree of personalized instruction, student autonomy, and competency-based instruction occurring in the lesson. An N code would indicate that the observers sees no evidence of student-centeredness in the activity.

Technology Integration Code. For this code, observers should note the extent to which technology allows students to learn in a student-centered fashion, or whether the students engage with the technology in a student-centered way. With the former, technology might allow students to learn in a student-centered fashion that would not be possible without the technology. For example, access to information may allow student learning to be individualized; access to multiple modalities of learning (e.g., video, written text) might allow for personalization, or a learning management system might allow student-teacher and student-student collaboration and/or student portfolios that promote competency-based learning.

Technology might also enable student centered teaching such that it enables the collection of data to support and inform individualized learning progressions. Technology-enabled assessments might allow for an organized collection of content, practice, and measurement items, as well as produce data on what students know, how they are progressing, and provide scaffolded support. Student and teacher portals would enable a way to organize and store work, develop portfolios, and manage learning and administrative tasks; student-student or student-teacher collaborative platforms would support communication and facilitate group projects.

- **No technology**: Students may have opportunities for autonomy, personalization or competency-based learning, but these opportunities are not related to any use of technology.
- **Minimally integrated**: Students have limited choice in when and how to use technology; teacher may demonstrate rather than having students do the activity; the activity could be completed without the technology and in some cases the technology interferes with student-centeredness. The technology itself does not contribute to autonomy, personalization or competency-based learning.
- **Partially integrated**: Students have options about how and when to use technology; the technology enhances student-centeredness by increasing autonomy (e.g., students have more choice about how to complete a task), personalization (e.g., allows material to be individualized to meet student needs); competency-based (e.g., students are evaluated when they are ready rather than en masse).
- **Fully integrated**: The technology allows students to learn in a student-centered fashion that would not be possible without the technology; access to information allows student learning to be individualized; access to multiple modalities of learning (e.g., video, written text) allows personalization; learning management systems allow student-teacher and student-student collaboration and/or student portfolios that promote competency-based learning. The technology promotes extensive use of individualized learning paths, assessment, organization, and collaboration systems that allow them to share their work, prepare portfolios, be assessed with adaptive systems.

Student-centered teaching example (Embedded student centeredness)	
No technology	Students complete worksheets asking them to compare and contrast various kinetic graphs (showing relationships between time and velocity). The teacher differentiates the assignment by providing graphs of varying levels of complexity for different groups of students, and worksheets are completed in pairs or small groups that may collaborate with each other. *Embedded: Students are able to collaborate, and worksheets are differentiated.*
Minimally integrated	Students complete a paper-based lab in which they use Vernier motion detectors to replicate kinetic graphs using their own bodies (showing relationships between time and velocity), but problems with the software interfere with the completion of the lab and/or detract from the lesson. The teacher differentiates the assignment by providing graphs of varying levels of complexity for different groups of students, and labs are completed in pairs or small groups that may collaborate with each other. *Minimal: Students use Vernier motion detectors, but problems with the technology end up interfering with the lesson, reducing its effectiveness.*
Partially integrated	Students complete a paper-based lab in which they use Vernier motion detectors to replicate kinetic graphs using their own bodies (showing relationships between time and velocity). The teacher differentiates the assignment by providing graphs of varying levels of complexity for different groups of students and labs are completed in pairs or small groups that may collaborate with each other. *Partial: The use of the Vernier motion detectors allows the students to immediately see and experience the relationships depicted in the kinetic graphs, thus enhancing the lesson.*
Fully integrated	Students complete an online lab through a Learning Management System (LMS) in which they use Vernier motion detectors to replicate kinetic graphs using their own bodies (showing relationships between time and velocity). The teacher provides graphs of varying levels of complexity for different groups of students and labs are completed in pairs or small groups that may collaborate with each other. Labs are completed and submitted through the LMS, which also allows student groups to collaborate with each other and discuss various aspects of their graphs online. The teacher is also able to grade the labs and provide feedback to the student groups through the LMS. *Full: The use of Vernier motion detectors and the LMS to collaborate and complete the assignment enable a level of personalized learning that would otherwise be very difficult to accomplishment without the technology.*

Contextualized Teaching. In this protocol, contextualized teaching is defined by incorporating lesson material related to the students or issues beyond the instructional setting. Three components we consider in our framework are:

- Relevant to youth experiences (e.g., topic and/or learning goals relate to contemporary events, youth culture, or cultural background),
- Linked to science careers or work (i.e., connection is made to science careers, career tracks, and/or the work of scientists), and
- Grounded in the local/geographical context.

Category Code. The observer should note whether contextualization occurs within one of the sub-categories (i.e., relevant to youth experiences, linked to science careers or work, or grounded in the local/geographic context) and document in the field notes/evidence column if/how this occurs.

Level. Observers should record the code I (Incidental Connection) or E (Embedded Connection) when observing teachers making youth-relevant, science career, and/or local connections. If observers have not observed any occurrence of any of the three contextualized teaching types, they should record N (No Connection). **Incidental** contextualization would occur when a teacher makes a brief reference or single statement, in order to connect what is being taught to youth experiences, science careers or the work of scientists, or to a local context. Evidence of **embedded** contextualization would be if the entire lesson is integrated and connected to something to which the students can relate (i.e., youth experiences, science careers or work, or their local area/geographic location).

Technology Integration Code. If technology is used to promote contextualized teaching, this should be briefly described in the field notes and evidence column and the appropriate technology integration code should be selected.

- **No technology**: Content is contextualized for students without the use of technology.
- **Minimally integrated**: The technology provides access to or information about contextualized content; this information could be communicated without technology
- **Partially integrated**: The technology provides access to or information about contextualized content; students use technology to manipulate the information, data or other resource in some way
- **Fully integrated**: The technology provides access to or information about contextualized content; students use technology to manipulate the information, data or other resource in some way. Students are able to engage with the contextualized information in a complex way that would not be possible without the technology. The activity may take place over multiple days in order to be immersed in the context.

Contextualized teaching example (connection to students' interest in local watershed)	
No technology	In a lesson about water conservation and what towns and cities are doing about cleaning up water, the teacher provides printed reading material from their local watershed organization's website. Students read about and discuss local water conservation and cleanup efforts. They can see the local watershed data on the printed material and look for patterns in the data. *No tech: printed material.*
Partially integrated	In a lesson about water conservation and what towns and cities are doing about cleaning up water, the teacher provides access to their local watershed organization's website. Students read about and discuss water conservation and cleanup efforts in their local watershed. They can see the watershed data online and look for patterns in the data. *Minimal: students reading teacher-provided information online which is similar to analog experience of reading on paper.*
Minimally integrated	In a lesson about water conservation and what towns and cities are doing about cleaning up water, the teacher provides access to their local watershed organization's website. Students read about and discuss water conservation and cleanup efforts in their local watershed. They can see the watershed data online and look for patterns in the data. The students download data for stream health and land cover in upstream watershed for their local stream site. They create scatter plots of the data to examine the relationship between stream health and land cover (i.e., percent impervious surface, percent forest, percent farmland, percent lawn). *Partial: The ability for the students to download, manipulate, and analyze the data allows the students to better understand the information and increase their interest in watershed health and needed conservation efforts.*
Fully integrated	In a lesson about water conservation and what towns and cities are doing about cleaning up water, the teacher provides access to their local watershed organization's website. Students read about and discuss water conservation and cleanup efforts in their local watershed. They can see the watershed data online and look for patterns in the data. The students download data for stream health and land cover in upstream watershed for multiple stream sites within their larger watershed. They create multiple scatter plots of the data to examine the relationship between stream health and land cover (i.e., percent impervious surface, percent forest, percent farmland, percent lawn), and examine how their site compares to others along the trend line. Students also gather information on cleanup efforts from the EPA web site. *Full: Students combine information across multiple sources for analysis.*

Part 3: Post-Observation Teacher Questions

Purpose

The purpose of these questions is to provide more context for what was observed, and give the observer the opportunity to follow up with the teacher with any questions that may have arisen during the course of the observation, and clarify the intentionality of observed teaching practices. Many of these responses will inform the post-observation summary.

Tip: Teachers should be asked these questions as soon as possible after the conclusion of the observation period. If there is not time immediately following the observation to interview the teacher, arrangements should be made for a phone call to discuss the follow-up questions.

Questions

1. **How representative of your usual technology use was the observed lesson/unit?**

   This question assesses the extent to which the teacher uses technology on a regular basis.

2. **In what ways do you feel the technology use in the observed lesson/unit was effective in helping students understand the big ideas?**

   This question will inform the post-observation summary regarding how and whether the technology use impacted student learning in the intended manner.

3. **Is there anything you would have done differently with regard to technology use?**

   This question addresses any technology challenges that may have unexpectedly arisen during the class, whether they were foreseen or unforeseen, how the teacher might address these challenges in the future, and whether the teacher felt the student learning was impacted by these challenges. This question will also inform the post-observation summary.

4. **How would the lesson be different if you taught it without technology? (If you have previously taught this or a similar lesson without technology, please describe the differences.)**

   This question addresses the intentionality of using technology for this particular lesson, and the extent to which the technology is integrated in the lesson. If the teacher has taught this lesson (content or skills) before without technology, has the addition of technology enhanced or transformed the lesson?

5. **Is there anything else we should know about the observed lesson/unit?**

   This allows the teacher to add any additional insights into the observed class period. The observer may learn more about intentionality of certain teaching practices that can inform their ratings for SEP, student-centered teaching, contextualized teaching, and technology integration.

6. **Other follow up questions.**

   Observers may have clarification questions after the observation.

Part 4: Post-Observation Code Summary Ratings

Content	Data source	1-3 sentence description
Name of course and grades of students	Pre-questions	
Big ideas students are working on and how teacher has designed technology to support those ideas	Pre- and post-questions	
Specific technology use in the lesson (e.g., hardware, software, activities students engaged in)	Pre-questions and activity sheets	
How this lesson fits in with other technology use; coherence of content and technology use	Pre-questions and activity sheets	
Challenges in lesson and how teacher addressed them (e.g., technology glitch, classroom management)	Activity sheets and post-questions	

	SEP	SEPtech	How technology contributed to student use and/or understanding of SEPs (Key evidence and 1-3 examples; note specific SEP as relevant)
Activity sheet 1			
Activity sheet 2			
Activity sheet 3 ...			
Average science and engineering practices score			

	SCT	SCTtech	How technology contributed to student-centered teaching (Key evidence and 1-3 examples; note autonomy, personalization, competency-based as relevant)
Activity sheet 1			
Activity sheet 2			
Activity sheet 3 ...			
Average student-centered teaching score			

	Context	Contexttech	How technology contributed to contextualization (Key evidence and 1-3 examples; note youth-focused, science-focused; time/place relevance as relevant)
Activity sheet 1			
Activity sheet 2			
Activity sheet 3 ...			
Average contextualization score			

Highest Activity sheet	Level	Tech	How technology contributed to each (Key evidence and 1-3 examples)
SEP			
SCT			
Content			

The *TOP-Science* protocol results in rich data describing technology integration in the classroom. Researchers are able to analyze the data in whatever way best serves to address their research questions; we have provided a format to summarize the results aligned with our framework. The post-observation summary provides a tool to synthesize the observations across the teacher pre- and post-questions and the multiple activity sheets. By placing the results of activity sheets together, researchers can see trends across all activity sheets. The quantitative results (summing together the numerical values of the codes) provide one indication of quality, but the qualitative results provide evidence for that quality.

The digital version of *TOP-Science* will include a system to automatically complete most of the cells on the summary document; this description applies to the non-digital format which requires observers to complete the summary document manually.

Qualitative description of classroom

For each of the five rows describing what happened during the classroom observation, the observer should use the identified data source to complete the brief description. This section provides prompts to describe key technology components of the classroom and will provide a standardized description of each classroom that focuses on teacher intentionality in technology integration.

Content	Data source	1-3 sentence description
Name of course and grades of students	Pre-questions	
Big ideas students are working on and how teacher has designed technology to support those ideas	Pre- and post-questions	
Specific technology use in the lesson (e.g., hardware, software, activities students engaged in)	Pre-questions and activity sheets	
How this lesson fits in with other technology use; coherence of content and technology use	Pre-questions and activity sheets	
Challenges in lesson and how teacher addressed them (e.g., technology glitch, classroom management)	Activity sheets and post-questions	

Summary of activity sheets by framework category

The summary provides space for both the quantitative codes and the qualitative evidence. Use the values indicated in the table below to complete each category and technology code column for each activity sheet, and then calculate the average score for all activity sheets.

Category code	Value	Technology code	Value
Not observed	0	No technology or NA	0
Incidental	1	Minimally integrated	1
Embedded	2	Partially integrated	2
		Fully integrated	3

Use the text from the "Evidence" section of each activity sheet to complete the Evidence section of the summary. Once all the evidence has been listed, synthesize the key evidence to provide an overall description of technology integration for each of the SEP, SCT, and Contextualization categories.

	SEP	SEPtech	How technology contributed to student use and/or understanding of SEPs (Key evidence and 1-3 examples; note specific SEP as relevant)
Activity sheet 1			
Activity sheet 2			
Activity sheet 3 ...			
Average science and engineering practices score			

	SCT	SCTtech	How technology contributed to student-centered teaching (Key evidence and 1-3 examples; note autonomy, personalization, competency-based as relevant)
Activity sheet 1			
Activity sheet 2			
Activity sheet 3 ...			
Average student-centered teaching score			

	Context	Contexttech	How technology contributed to contextualization (Key evidence and 1-3 examples; note youth-focused, science-focused; time/place relevance as relevant)
Activity sheet 1			
Activity sheet 2			
Activity sheet 3 ...			
Average contextualization score			

Highest activity sheet

The last section of the summary provides an opportunity to focus on the activity sheet that describes the highest overall levels of the codes. This allows researchers to highlight particular moments of the class that illustrate high quality technology integration.

Highest Activity sheet	Level	Tech	How technology contributed to each (Key evidence and 1-3 examples)
SEP			
SCT			
Content			

By providing the average scores across activity sheets as well as the highest level ratings, the post-observation summary allows the protocol to be flexible in how researchers can use the summary data, depending on their own qualitative or quantitative analyses.

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Appendix A.

Technology Definitions

The *TOP-Science* protocol defines technology as the hardware and software involved with digital technology. We are more interested in the software, or technology applications, that may be used in high school science classrooms, but also consider the hardware that runs the particular digital software.

We understand that the term technology in the context of education and instruction has many varied definitions, and considered them when determining what we ultimately included in our own definition. Some of the definitions we reviewed are listed below:

- Instructional technology (Seels & Richey, 2012): "In its more familiar sense it means that media born of the communications revolution which can be used for instructional purposes alongside of the teacher, textbook and blackboard...the pieces that make up instructional technology: television, films, overhead projectors, computers and other items of 'hardware' and 'software'..." (p. 17).
- Educational technology (Januszewski & Molenda, 2013): Technology "resources, the hardware and software entailed in teaching… The pool of resources has expanded with technological innovations and with the development of new understandings regarding how these technological tools might help guide learners. Resources are people, tools, technologies, and materials designed to help learners. Resources can include high-tech ICT systems, community resources such as libraries, zoos, museums, and people with special knowledge or expertise. They include digital media, such as CD-ROMs, Web sites, WebQuests, and electronic performance support systems (EPSS). And they include analog media, such as books and other print materials, video recordings, and other traditional audiovisual materials" (p. 11-12).
- Educational/instructional technology (Subramony, 2008): "Educational/instructional technology, as used in this paper, refers to the growing range of human-engineered tools—both products and processes—employed within educational contexts towards the ultimate goals of promoting and enhancing student learning" (p. ?)
- Instructional/educational technology (Newby, Stepich, Lehman, & Russell, 2000): Application of scientific knowledge about human learning to the practical tasks of teaching and learning.
- Educational technology integration (van't Hooft, 2009): "The process of utilizing digital technologies for teaching and learning" (p. 456)
- Technology applications (Ololube, 2015): "The application of technology tools and devices in the teaching and learning processes. It involves the usage, knowledge, skill and competence in the use of technology in solving problems or performing specific functions during and after academic activities" (p. 130)