THE EFFECT OF COMPUTER SUPPORTED CONTINUOUS FORMATIVE ASSESSMENT ON STUDENT LEARNING IN STEM CLASSROOMS

A dissertation in partial fulfillment of the requirements
For the degree of
Doctor of Education in Educational Leadership

By
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December 2014
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Dedication

To my loving wife, Lynn
Acknowledgements

This work could not have been realized without the generous allotment of time and input from CSUN, CSM and LAUSD teachers and professors who served as subjects in this study. The interviews with them provided me with a picture of their most sincere goals in their teaching practices. They all came with a desire to improve student learning success. They relayed a sense of commitment that went beyond what is expected in a faculty contract. Their genuine dedication was a profound inspiration to me.

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Finally, I want to express my sincerest appreciation for the support I received from my family, and close friends; to my late wife Cathy who lovingly supported me in our many years together and to my dearly departed parents, Joyce and Martin whom I know are smiling proudly. In particular, I want thank my loving wife Lynn who spent many hours proofreading and calming an anxious husband.
Table of Contents

Signature Page .......................................................................................................................... ii
Dedication ............................................................................................................................... iii
Acknowledgements ............................................................................................................... iv
List of Figures ....................................................................................................................... viii
List of Tables ......................................................................................................................... vii
Abstract ................................................................................................................................... x

Chapter 1: Introduction ......................................................................................................... 1
  Motivation ............................................................................................................................ 1
  Engagement ......................................................................................................................... 2
  Metacognition ..................................................................................................................... 3
  Accountability ..................................................................................................................... 4
  Collaboration ....................................................................................................................... 4
  Purpose and Significance .................................................................................................... 8
  Formative Assessment ....................................................................................................... 9
  Overview of Methodology ............................................................................................... 16
  Limitations and Delimitations .......................................................................................... 17
  Research Questions ......................................................................................................... 18
  Examples of CFA Techniques ......................................................................................... 20
  Traditional Formative Assessment ................................................................................... 24
  Survey Questions ............................................................................................................. 26
  Theoretical/Conceptual Framework .................................................................................. 26

Chapter 2: Literature Review .............................................................................................. 28
  Sources ............................................................................................................................... 29
  Methodologies used in the Literature .............................................................................. 29
  Urgency .............................................................................................................................. 30
  Implications ....................................................................................................................... 33
  Cost Issues ......................................................................................................................... 35
  Formative Assessment ...................................................................................................... 36
  Types of Formative Assessment and Their Effectiveness ................................................ 39
  Cloud Technologies and Formative Assessment ............................................................. 49

Chapter 3: Methodology ...................................................................................................... 53
  Basic Research Concepts ................................................................................................ 55
  Research Questions ......................................................................................................... 56
  Protocol Design ................................................................................................................ 56
  Subjects .............................................................................................................................. 59
  Observations ..................................................................................................................... 60
  Interviews .......................................................................................................................... 60
  Action Research .............................................................................................................. 61
  Surveys ............................................................................................................................... 62
  Ethical Considerations ...................................................................................................... 64
  Summary ............................................................................................................................ 64
List of Tables

Table

1  Graduation Rates For Full-Time, First-Time Freshmen Declaring Majors in STEM Fields in the CSU System ................................................................................................................. 8

2  Description of the subjects and the classes in which they were observed .............. 59

3  Responders’ perceived effectiveness of CFA: Reporting as CSUN students. 141 survey-takers responded .................................................................................................................. 142
List of Figures

Figure

Figure 1. Percentage of students entering post-secondary education as STEM majors in the years between 1981 and 2011 .................................................................................. 6

Figure 2. Venn diagram displaying the intersection of features characteristically found in Continuous Formative Assessment ................................................................. 14

Figure 3. An online Quick Write with Student Responses to Teacher Prompts ............ 21

Figure 4. Collaborative Data Plot of Mass/Volume Ratios Revealing a Clear Trend ...... 23

Figure 5. The Readiness Gap by College Access Level ................................................. 32

Figure 6. An example of the Frayer Model .................................................................. 128

Figure 7. Student renderings of 60 degree reference angles in a unit circle ............... 138

Figure 8. Student Renderings Describing an Architectural Site ................................. 138

Figure 9. Student Renderings Showing Translations of a Cosine Curve ................. 138

Figure 10. Student Renderings of a Cosine Curve Correcting for Horizontal Axis Labels .................................................................................................................. 138

Figure 11. Teacher Reported Exposure Levels to CFA Techniques as Students ........ 141

Figure 12. Responder’s Predicted Level of Student Engagement ............................... 146

Figure 13. Responders’ Predicted Level of Awareness of Student Understanding .... 146

Figure 14. Responders’ Predicted Awareness of Student Misconceptions ............... 147

Figure 15. Teachers Predicted Rankings of The Next Generation Science Standards in Classes Taught With CFA vs. Classes Taught with TFA. The vertical axis represents number of respondents ......................................................................................... 148

Figure 16. Teachers Predicted Rankings of Motivation Characteristics in Classes Taught with CFA vs. Classes Taught with TFA ................................................................. 149

Figure 17. Respondents Predicted Tendency to make Adjustments in Classes Taught with CFA vs. Classes Taught with TFA ........................................................................ 151

Figure 18. Experienced Teacher Reported Usage Levels of CFA Techniques ............ 152
Figure 19. Experienced Teachers’ Reported Awareness of Student Level of Engagement ................................................................................................................................. 153

Figure 20. Experienced Teachers’ Rankings of Motivation Characteristics in Classes Taught with CFA vs. Classes Taught with TFA ......................................................................................................................... 154

Figure 21. Experienced Teachers’ Reported Awareness of Student Understanding in TFA and CFA Taught Classes ................................................................................................................................. 155

Figure 22. Experienced Teachers’ Reported Awareness of Student Misconceptions in TFA and CFA Taught Classes ................................................................................................................................. 155

Figure 23. Experienced Teachers’ Tendency to Make Adjustments in Classes Taught with CFA vs. Classes Taught with TFA ................................................................................................................................. 157

Figure 24. Experienced Teachers Rankings of the Next Generation Science Standards in Classes Taught with CFA vs. Classes Taught with TFA ................................................................................................................................. 158
ABSTRACT

THE EFFECT OF COMPUTER SUPPORTED CONTINUOUS FORMATIVE ASSESSMENT ON STUDENT LEARNING IN STEM CLASSROOMS

By

Martin C. Tippens

Doctor of Education in Educational Leadership

Why do students drop out of STEM courses and majors? Issues of motivation are recognized in the literature as primary reasons students struggle in STEM courses. This dissertation establishes a connection between formative assessment and student success in STEM courses. The study begins with best practices in formative assessment as noted by experienced teachers and then proceeds to evaluate internet cloud-based methods known as Continuous Formative Assessment (CFA) in their effectiveness in dealing with a list of parameters known to be related to student motivation including; engagement, metacognition, accountability, and collaboration. As well, the effect of CFA to promote Dimension 1 of the Next Generation Science Standards is reviewed. In addition, CFA techniques are perceived to be of particular value in engaging students and informing teachers of students’ level of cognition with respect to course material.
Chapter 1: Introduction

In this dissertation, two compelling problems in STEM education are examined and a proposed treatment applicable to both issues is given detailed review. The problems are (1) STEM courses act as gatekeepers to success for students of any major and (2) retention rates of students who enter STEM majors are low. In chapter 2, issues of motivation are identified in the literature as primary reasons students struggle in STEM courses. Formative assessment is also acknowledged in educational studies as an effective method in addressing and improving motivation of students in STEM courses. I suggest a transitive relation between formative assessment and student success in STEM courses. Best practices in formative assessment are then put into focus. Traditional and new internet cloud-based methods are evaluated and given consideration in their effectiveness in dealing with a list of a parameters expanded from student motivation to include; engagement, metacognition, accountability, and collaboration. Subsequent paragraphs are dedicated to the definition and details of these parameters.

Motivation

Towards the objective of reducing the number of students that stop-out as a result of post-secondary math and science requirements, many studies identify student motivation as a key component to achievement in STEM courses (Alfassi, 2003; Chemers et al., 2001; Ramos-Sanchez & Nichols, 2007; Stinson, 2004). Eccles and Wigfield (2000) define an expectancy-value theory of motivation in terms of specific constructs including expectancies for success, perceived difficulties of assignments, beliefs in ability (self-efficacy), and the individual valuation of tasks. “Theorists in this tradition (expectancy-value theory) argue that an individuals’ choice, persistence, and
performance can be explained by their beliefs about how well they will do on the activity and the extent to which they value the activity” (Eccles & Wigfield, 2000, p. 68).

Studies often partition motivation into categories given as *intrinsic* and *extrinsic* motivation (Ryan & Deci, 2000; Eccles & Wigfield, 2000; Weiner, 1985). The intrinsic variation is characterized by its internally gratifying nature. One is compelled to complete the task as it is found enjoyable. Extrinsic motivation is that which compels one to achieve in order to reach a desired outcome (Ryan & Deci, 2000). In the teacher/student dynamic, motivation is frequently of an extrinsic nature. As such, it is often deemed as the less desirable form of motivation – however effective. It has been proposed by authors Ryan & Deci (2000) that this is not always the case. “Students can perform extrinsically motivated actions with resentment, resistance, and disinterest or, alternatively, with an attitude of willingness that reflects an inner acceptance of the value or utility of the task” (Ryan & Deci, 2000, p.55). As students proceed through their academic years, intrinsic motivation diminishes as requirements for more involved and encompassing learning responsibilities increase. The desired result is an internalization and integration of principles such that the student personalizes instruction (Deci & Ryan, 2000).

**Engagement**

Engagement is a blend of student behavioral and emotional dispositions. For clarity it is juxtaposed against passiveness or disaffection and denotes an elevated level of concentration and passion for the learning exercise (Connell & Wellborn, 1991; Skinner, 1991). In describing the engaged student, Skinner & Belmont (1993) write:
Children who are engaged show sustained behavioral involvement in learning activities accompanied by positive emotional tone. They select tasks at the border of their competencies, initiate action when given the opportunity, and exert intense effort and concentration in the implementation of learning tasks. (p. 572)

Ideally, engagement leads to personal fulfillment and increased aptitudes. Indeed, studies have shown that engagement is positively correlated to increases in academic ability (Marks, 2000; Skinner, Wellborn, & Connell, 1990).

**Metacognition**

The impact of metacognition as an indicator of learning has been an enduring topic in the literature on education (Kim, Ryu, 2013; Thompson, Turner, Pennycook, 2011; Wang, Haertel, & Walberg, 1990; Flavell, 1977; Flavell & Wellman, 1979). The discourse is far from settled concerning the definitive meaning, properties and mental processes of *metacognition*. In addition, there are many questions on the distinction between cognition and metacognition (Veenman, Van Hout-Wolters, Afflerbach, 2006). A generally accepted working-definition is that *metacognition* is “higher order cognition about cognition” (Veenman et al., 2006, p. 5) or “knowing about knowing” (Metcalfe & Shimamura, 1996, p.1). The definition is further distilled into a number of specific areas, two of which are found to be appropriate to this study. They are; *metacognitive processes* pertaining to the internal evaluation of learning and *metacognitive awareness* addressing the problem solving questions one asks of oneself or “what to do when” (Afflerbach, 2006; Alexander, Schallert & Hare, 1991; Van Hout-Wolters & Desoete & Roeyers, 2003; Veenman, Schraw & Moshman, 1995). Metacognition has been advocated as a fundamental indicator of learning (Wang, Haertel, & Walberg, 1990).
Accountability

Student accountability is referred to in this study in three contexts; to peers, to the teacher, and to one’s own learning. The initial two are characterized by a student’s answerability to external groups and individuals seeking a level of performance from the student towards the achievement of given responsibilities and commitments (Davis, Mero, & Goodman, 2007; Schlenker, Britt, Pennington, Murphy, & Doherty, 1994;). A student who has achieved a level where they are accountable to their own learning refers to one who has realized ownership of learning, a state of being described as “the intersection between taking responsibility, finding a personal value and feeling in control” (Enghag & Niedderer, 2008, p. 630).

Collaboration

Collaboration in the STEM environment is a synergistic collection of technical skills and resources deployed towards research (Bozeman & Corley, 2004). In a qualitative study conducted at a northeastern domestic midsize university (Palmer, Marimba & Dancy, 2011), researchers sought to identify factors that led to retention, persistence and success of students of color in STEM programs at a predominantly white institution. The researchers found, “formative experiences provided by peer engagement and participation in STEM-related activities” (p. 501) among the three themes acknowledged as most important towards the student’s success in STEM majors. The study further expressed that students in peer learning environments felt more at ease to ask questions. The peer learning practice fostered encouragement, motivation, self-efficacy and strengthened the student’s resolve to remain with their STEM major.
In editor Alan Seidman’s collection of research articles on student retention entitled *College Student Retention* (2005), authors John Braxton and Amy Hirshy surmised that, “Faculty who intentionally involve class members in the learning process…contribute to student persistence” (Braxton & Hirschy, 2005, p. 78). Subsequently, the authors included collaborative learning projects and peer group work among a short list of ways to promote active learning.

A large collection of teachers identified major advantages in formative assessments performed with the aid of cloud-based programs and applications compared to traditional formative assessment methods. The advantages noted in each of the parameters listed above, excel to the degree that they represent a significant transformation in the pedagogy of teaching STEM courses.

**Problem statement.** As a professor and department chair at Woodbury University’s (WU) Mathematics Department, I have found that math often serves as a gatekeeper course towards student success and often results in costly delayed graduation for many students. The prevailing research indicates the problem is not at all unique to the WU student body. Seventy percent of California Community College students, with similar enrollment demographics to WU students, are placed in remedial math courses (RPGCCC, 2005, p. 6). The current transfer rate from a California Community College (CCC) to any four-year institution hovers around forty to forty-one percent. (CCCCO report, 2007). Nearly sixty percent of students enrolling in the California Community College system are not moving on to a 4-year institution.

Math also serves as a gatekeeper for those choosing majors in science, technology, engineering and mathematics (STEM). The National Math and Science
Initiative (NMSI) reports a diminishing number of college students graduating in STEM subjects as “one of this nation’s greatest economic and intellectual threats.” (NMSI, para. 1, n.d.). In the emerging global market, it is to our great national benefit to improve the aptitudes of our students in the universal language of mathematics. Unfortunately, students are leaving U.S. high schools underprepared to meet the mathematics requirements of the nation’s four-year institutions (RPGCCC, 2005).

The Higher Education Research Institute (HERI) at the University of California Los Angeles (UCLA) shows the number of students entering post-secondary education as STEM majors has been increasing nationwide over the last several decades. Figure 1 displays data recorded by the HERI national survey of hundreds of thousands of students at over 200 baccalaureate granting institutions (HERI, 2012a, 2012b, 2012c, 2012d).

![Figure 1. Percentage of students entering post-secondary education as STEM majors in the years between 1981 and 2011.](image)
While the number of students enrolling in STEM majors is on the rise, it is still relatively low in comparison with other non-STEM majors. The bigger problem is that the number of students graduating in these majors is low. This unfortunate trend was discussed at length in *Talking About Leaving*, a 1997 book that noted a disproportionate percentage of students switching out of STEM majors. In a study of unpublished data provided by the HERI survey, the authors found more than forty-seven percent of science majors and sixty-three percent of mathematics majors switched out of their majors. This was compared to social science, history, fine arts and education majors who changed majors at percentage rates only as high as thirty-five percent. The lowest switching rate was fifteen percent for English majors. The greatest number of students switching from STEM majors occurred in the freshman to sophomore year transition (Hewitt & Seymour, 1997, pp. 3-15).

The figures in Table 1 were reported by the California State University (CSU) system from data collected by The Consortium for Student Retention Data Exchange (CSRDE) at the University of Oklahoma. The Table gives the graduation rates for full-time, first-time freshmen declaring majors in STEM fields in the CSU system. It shows that, at best, only thirty-nine percent of students starting their college experience in a STEM field will graduate in that field within 6 years (CSU, 2012).
Table 1

Graduation Rates For Full-Time, First-Time Freshmen Declaring Majors in STEM Fields in the CSU System

<table>
<thead>
<tr>
<th>Year</th>
<th>All Students</th>
<th>Female</th>
<th>Male</th>
<th>Black</th>
<th>Hispanic</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>0.268</td>
<td>0.256</td>
<td>0.275</td>
<td>0.091</td>
<td>0.196</td>
</tr>
<tr>
<td>2001</td>
<td>0.25</td>
<td>0.248</td>
<td>0.251</td>
<td>0.083</td>
<td>0.161</td>
</tr>
<tr>
<td>2002</td>
<td>0.282</td>
<td>0.262</td>
<td>0.292</td>
<td>0.127</td>
<td>0.165</td>
</tr>
<tr>
<td>2003</td>
<td>0.287</td>
<td>0.271</td>
<td>0.296</td>
<td>0.133</td>
<td>0.199</td>
</tr>
<tr>
<td>2004</td>
<td>0.318</td>
<td>0.289</td>
<td>0.334</td>
<td>0.128</td>
<td>0.217</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Asian</th>
<th>American</th>
<th>Non-resident</th>
<th>White</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>0.252</td>
<td>0.178</td>
<td>0.314</td>
<td>0.33</td>
</tr>
<tr>
<td>2001</td>
<td>0.223</td>
<td>0.255</td>
<td>0.34</td>
<td>0.32</td>
</tr>
<tr>
<td>2002</td>
<td>0.269</td>
<td>0.189</td>
<td>0.284</td>
<td>0.363</td>
</tr>
<tr>
<td>2003</td>
<td>0.266</td>
<td>0.2</td>
<td>0.26</td>
<td>0.357</td>
</tr>
<tr>
<td>2004</td>
<td>0.31</td>
<td>0.327</td>
<td>0.302</td>
<td>0.393</td>
</tr>
</tbody>
</table>

Additional CSRDE data shows that four-year graduation rate averages six percent. Just as alarming are the figures showing that sixty percent of students starting STEM majors in the CSU system do not continue in their major past four years (CSU, 2012).

Purpose and Significance

In search of a cause for this excessive migration from STEM subjects, Hewitt and Seymour (1997) performed a three-year longitudinal study of 335 students attending a sampling of seven different four-year institutions across the nation. Through focus-group and individual student interviews, they learned that the top four reasons for leaving were identified as; “lack or loss of interest in science, belief that a non-STEM major holds more interest, (and) poor teaching by STEM faculty” (Hewitt & Seymour, 1997. p. 32).
The authors put additional focus on teaching:

The experience of conceptual difficulty at particular points in particular classes, which might not constitute an insuperable barrier to progress if addressed in a timely way, commonly sets in motion a downward spiral of falling confidence, reduced class attendance, falling grades, and despair-leading to exit from the major. (Hewitt & Seymour, 1997, p. 35)

In this case, the “lack of a timely response” represents a failing of traditional STEM teaching. Their observation is a call to teachers to more continuously evaluate a student’s understanding of the concepts presented in a STEM course. “Such regular assessment can catch student misconstructions of basic ideas before such confusions ascend to hopelessness. Effective retention of students results when student performance is more closely monitored” (West, 1991, p.67). The mention of falling confidence in the Hewitt and Seymour quote (1997), is echoed in further research indicating that many students leave STEM majors due to lack of self-efficacy and motivation (Onwuegbuzie, 2000; Street, 2010). This is predominantly the case with women and minority groups who enroll in STEM majors at rates comparable to White males and Asian Americans but leave the majors at significantly higher rates (Anderson, 2006; Malicky, 2010).

**Formative Assessment**

The evaluation of student understanding of course material performed at regular intervals by an instructor is known as Formative Assessment. It informs the learning of the student and the teacher in concert. Authors Beverly Bell and Bronwen Cowie (2000) provide an appropriate working definition of formative assessment as, “The process used by teachers and students to recognize and respond to student learning in order to enhance
that learning, during the learning.” Their definition implies an aspect of continuity in formative assessment where teaching takes on real-time dynamics. The more often a teacher can tap the student’s level of cognition, the more opportunity the teacher has to adjust the instruction to foster the learning (Fallon & Forest, 2011; Maegregor et al., 2011; Stull, Majerich, Bernacki, Jansen, Varnum, & Ducette, 2011).

The literature has spoken to the advantages of formative assessment as it has been implemented in traditional ways such as regular quizzes (Black & Wiliam, 2009; Shepard, 2005; Stull, Majerich, Bernacki, Jansen, Varnum, & Ducette, 2011). Regular quizzes can develop mastery in the learning and give the teacher an indication of where the students are retaining the taught concepts and where they are not. To further clarify the purpose and value of formative assessment, it is helpful to juxtapose the concept with other forms of assessment. Commonly employed in STEM courses as a measure of learning accountability are Summative Assessments. Summative assessments most often take the form of tests at the end of a significant period of instruction. Examples are chapter tests and course midterms and finals. While learning can result from the output of summative assessments, it is not the primary purpose. Fundamentally, summative assessments are “high stakes” diagnostic tests that gage the student’s degree of mastery with regards to a substantial section of course content. They take the form of course final exams and local, department and statewide program learning evaluations (Perie, Marion, Gong & Wurtzel, 2007).

Interim Assessments such as chapter tests and quizzes also provide the instructors with information on the student’s understanding of course content (Perie, et al, 2007; Pinchok & Brandt, 2009). Yet, while interim and summative assessments are informative
to the instructor and student alike, their benefits to learning are not delivered at moments when adjustments can be made to correct or confirm the students understanding of the material (Herr, Rivas, Chang, Tippens, Vandergon, d'Alessio, & Nguyen-Graff, 2014). More beneficial to the learning is the type of assessment a teacher performs during class discussions. When such valuation practices are embedded in the instruction, it is known as *Formative Assessment* (Black & Wiliam, 2009). Formative assessment has been shown in existing literature to improve student learning success (Black & Wiliam, 2009; Shepard, 2005) and is significantly effective with at-risk students. It reveals learning deficiencies before the student has reached the point of no return (Achinstein & Athanases, 2003).

Formative assessment is not a new technique. In traditional face-to-face classrooms, teachers naturally engage in regular monitoring of student cognition. This takes place, for example, whenever an instructor asks the class a question and adjusts instruction as the result of student responses (Popham, 2008; Shepard, 2005). With the advent of distance learning and hybrid learning environments, questions of how best to monitor student cognition of program content arise (Herr, Rivas, Chang, Tippens, Vandergon, d'Alessio, & Nguyen-Graff, 2014). One solution is offered by textbook publishers. Currently packaged with many textbooks are online quizzes and tutorials that allow students to check their mastery of each concept presented in the text. When a student finds they’ve answered an exercise incorrectly, the programs often have tutorials the student can view to correct their misconceptions (Hoon, Chong & Ginti Ngah, 2010).

One concern with online environments is that, by their nature, they can be restrictive of the teacher/student dynamic (Wang & Woo, 2007). In an asynchronous
online environment, for instance, the role of the professor moves more towards that of a facilitator. This would be the case with textbook centered automated web-based mastery learning programs (Cremer, 2001). The advantage of immediacy in face to face classroom discussion is also lost in an asynchronous online environment. While more thought can be given in asynchronous discussions, they are less effective when conclusions are to be reached within a short time frame. The delayed response component of asynchronous communication is at odds with the desire to provide timely feedback and can promote and increase in frustration. In addition, students are deprived the benefit of multidirectional interactivity that invites additional corresponding and illuminating comments by peer students (Wang & Woo, 2007).

Technology based formative assessment practices can activate student learning and promote classroom engagement (Roschelle, Penuel & Abrahamson, 2004). This is of particular value in blended and strictly online course settings. Where technology has been mentioned in the literature on formative assessment, it is generally in terms of emails or clickers (Fallon & Forest, 2011; Macgregor et al., 2011). These technologies have excellent advantages in culling responses from students who might not participate in a more traditional classroom setting. However, they are somewhat limited in their abilities for spontaneous use and insight in the students thinking processes (Herr, Rivas, Chang, Tippens, Vandergon, d'Alessio, & Nguyen-Graff, 2014).

New internet cloud-based technologies afford a more continuous type of formative assessment about which data and literature are currently underrepresented. Such cloud-based applications now exist that allow students to collaborate, gather and report experimental findings on web based documents. Many of these undertakings can
be performed in the moment, just as regularly as a teacher would question the class on
topics that come to mind during instruction.

The actions being reported in real time, as data is collected, affords the instructor
a window into the students thinking processes. In this way, formative assessment is
embedded in the instruction. The cloud-based techniques require each student to input a
response to a teacher’s prompt or submit data in the process of an experiment. This
increases student accountability beyond that which an instructor would find by asking for
a show of hands. A noteworthy feature in this exercise is that a permanent record of
student progress is automatically created. This is of importance in documenting student
learning progress. There is a potential collective advantage as students see their own
work among the work of their peers. This allows the student to evaluate their responses to
teacher prompts with respect to the answers shown by other students. Also, the instructor
can point out exemplars among the student responses in guiding the learning. This model
of formative assessment has been termed Continuous Formative Assessment (CFA)
(Herr, Rivas, Chang, Tippens, Vandergon, d'Alessio, & Nguyen-Graff, 2014). Each of
these features, collective display of student work, accountability, in-the-moment
assessment and the permanent record of learning, is found more regularly in CFA
methods and as such, delineates CFA from traditional formative assessment (TFA). CFA
methods can be performed in face-to-face classrooms or in strictly online environments
such that distances between students, their peers and the teacher are not a factor. A recent
publication notes that, “These activities help students gain an understanding that the
learning enterprise requires collaboration, independent verification, and peer review”
CFA techniques were developed to promote students’ engagement, motivation, accountability, metacognition, and to realize the benefits of collaboration with their peers. With CFA techniques, students begin to think about their own thinking. Teachers can see if student comprehension of course material is on track. Students can see if they have full comprehension of course material and whether their thinking is corresponding with the teacher’s and other students. Instructors apply CFA methods as often and as spontaneously as they would the standard classroom art of questioning. However, instead of asking for a show of hands where many students withhold participation, all students are required to submit answers. This increases their level of accountability to their own learning (Herr et al., 2014).

One of the larger national trends in student learning, that of The Next Generation Science Standards (NGSS), lends elements of applicability and credibility to the learning and teaching advantages of CFA. The NGSS were developed through collaboration.
between leading national science research and educational organizations including the National Science Teachers Association, the American Association for the Advancement of Science, and the National Research Council. These organizations worked in concert with 26 states and corresponding state science education and research institutions. The public was also given a voice in review of the standards (Gillis, 2013; “Next Generation Science Standards”, 2013; Revkin, 2012; Robelen, 2012). The standards were proposed to generate collective standards for the teaching of STEM subjects and endeavored to encourage increased enrollment in STEM majors (Gillis, 2013). Drafts were released in 2010 and the final version was published in April 2013 (NGSS 1, 2013). Currently California is included among twelve states and the District of Columbia that have adopted the standards (Heitin, 2014).

Where CFA could have application to the NGSS is found in the motivation of their development. The standards were created to address the poor performance of the STEM education system in the U.S. noted in the initial paragraphs of this chapter (also see NGSS 3, 2013). They are a national call to STEM learning accountability for k-12 education. Any teaching method shown to hold promise in assisting learning to meet the NGSS standards would be of value. CFA is examined in this study with that intent in mind.

The metacognitive aspect of CFA concerns student questions. Students are often under the impression that it is the teacher’s responsibility to ask the questions (Ciardiello, 1993). Yet researchers have found that, “question asking is one of the most fundamental skills in learning that affects comprehension and problem solving” (Jonassen, 2010, p. 159). Students asking good questions are one of several indicators of learning
achievement listed under Dimension 1 of the *Next Generation Science Standards* (NGSS 2, 2013). CFA allows the instructor to monitor the questions students ask.

**Overview of Methodology**

This study surveys in-service and pre-service teachers enrolled in teacher education programs primarily at California State University Northridge (CSUN) that are being trained in educational applications of CFA. These in-service teachers have taught STEM courses for a number of years and have been exposed to and have practiced various types of formative assessment. The pre-service teachers are taking credential courses and are exposed to CFA techniques as learners in CSUN credential courses.

The qualitative and quantifiable survey data was processed using a within subjects ex-post facto design. This design is appropriate in instances where a longitudinal treatment and control group evaluation is not possible. The ex-post facto element is applied in instances where the subjects have experienced changes in environment. The data collection relies on subject reflection of past and present experiences. The pre-environment in this study refers to the subjects’ past classroom experiences both as learners and as teachers. The post-environment refers to their classroom experience after the CSCS course in CFA, again as learners and as teachers. The within subjects pre-experimental design element is applied in this case where a pre-survey is administered to the subjects. They are then given a treatment in the form of the CFA classroom experience and training. Subsequently they will take a post-survey. The self-reported perceptual data gathered in the surveys will disclose tendencies that will support or fail to support the suggested advantages of CFA. The data is processed in a qualitative fashion with clear trends in teachers’ opinions supported by pie charts and bar graphs.
Limitations and Delimitations

In an effort to determine the effectiveness of CFA, one could perform a longitudinal study using control and test groups and hard data such as (1) recorded scores on standardized tests; (2) correlations between various treatments of formative assessment on persistence in STEM. At a minimum, data would be gathered from two sections of the same science course. One group of students would receive the treatment of CFA instruction and the control group would be instructed with traditional methods of formative assessment. These could show more directly the advantage or disadvantage of CFA. Over time, the researcher could determine whether significant trends of improved student learning based on summative assessments resulted from the experiment or not. However, the term for this study is limited to one or two semesters. With such a time constraint, a longitudinal study of test and control groups would be incomplete. Hence, this study is approached as a preliminary step that could well inform a further more lengthy and inductive investigation.

The within-subjects design does not require a longitudinal format. The researcher can make repeated observations on individual subjects and groups of subjects. For example, how well a particular method of formative assessment would hypothetically work in class is weighed against views of teachers who have had the opportunity to actually use various methods of formative assessment in their teaching practice.

I well understand that ex-post facto design is not confirmatory and does not bear the status of models fit by controlled data (Cliff, 1983). The cause of improvement to learning, let alone student retention and success, as a result of applied treatments of CFA cannot be determined with any certainty regardless of perceived effectiveness. There are
far too many variables at play. Alternatively, when test and control group methods are not feasible, such as in this case where teacher subjects employed self-selected levels of formative assessment techniques, an appeal for possible relationships amid the variables can be reasoned (Diem, 2002). With this method, clusters of survey data revealed a pattern. As the data developed, difficulties as well as advantages in employing various formative assessment methods were exposed.

**Research Questions**

The research questions for this study are:

1. What are the perceived influences of continuous formative assessment using collaborative cloud-based technologies (CFA) on student engagement, motivation, collaboration, metacognition, and accountability in STEM classrooms?

2. What are the implications of CFA for reaching the learning goals expressed in Dimension 1 of the Next Generation Science Standards?

In this paper, the “quality of STEM education” is defined as the level of ability with which CFA is effective in meeting the learning goals given in Dimension I of the NGSS. In 2011, the National Research Council (NRC) published the *Framework for K-12 Science Education* which argued for a new set of State Standards in science education. The NRC authors argued that new educational standards in the sciences were needed to address the major advances that have occurred in the fifteen years since the last standards were established.
The learning goals were derived from Dimension 1 of the Next Generation Science Standards (NGSS, 2012). The survey questions sought responses illustrating where teaching quality and student learning had improved in areas including:

- Asking questions
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations (for science) and designing solutions (for engineering)
- Engaging in argument from evidence
- Obtaining, evaluating and communicating information

One aim of the NGSS standards is to further STEM subjects in their relevance and applicability to the next generation of students. Cooper and Padilla (2012) editorialize that, “The evolution of inquiry to the new conception of practices will require a reformulation of how we talk and think about science teaching and how we go about getting students to think about the science they learn” (p.7). Another purpose of the NGSS is the enhanced integration of sciences via common principles such as cause and effect and structure and function (Wysession, 2013). The CFA techniques are designed to meet this change in pedagogy (Herr, & Rivas, 2013).
Examples of CFA Techniques

An illustration of three popular CFA techniques is given in this section. This is in no way a complete list and new cloud-based teaching applications are being developed daily. In addition, there exist additional variations of the three techniques presented here:

1. **Online Quick Write** (also performed in Google Docs Spreadsheet application) - The online Quick Write (Figure 3) is a spreadsheet for which each student in the classroom has input capability. It operates as a more flexible variety of the classroom response system (CRS) such as *clickers* in that it allows for typed input from the students. The teacher instructs each student to type their name in a row under the column with header assigned to names. The remaining column headers will be given to teacher generated questions. Students will input their responses in the cells of their corresponding rows. While smartphone CRS apps such as *Socrative* are also capable of receiving this type of input, the advantage of the Quick Write is in its spreadsheet format presentation. The spreadsheet allows for all questions to remain projected to the class for further review. The spreadsheet is also more conducive to questions a teacher generates in the moment.
Figure 3. An online Quick Write with Student Responses to Teacher Prompts

As with a CRS, it provides the instructor with a comprehensive view of students’ thoughts, understandings and misunderstandings. It promotes engagement and accountability as each student is required to give input. It removes the common traditional class characteristics of the “smart kid” being the primary or only responder to teacher questions.

2. **Scan and Post** – This method expands further on the CRS concept by affording students the ability to upload hand drawn illustrations. This is of particular value in subjects that do a good deal of communication through graphing/mapping and symbolic notation. A physics teacher, for example, could quickly review the work of a class who are asked to draw the force vectors acting on an object in a static equilibrium problem. A calculus teacher can assess the work of a class assigned to evaluate an integral. This is possible as students scan their work and send it to a class-assigned cloud storage app such as *Dropbox* or *Picasaweb*. The teacher then projects the student contributions to the class. Contributions can be projected anonymously though...
student identification is easily achieved by the teacher as email address information is available for each submitted illustration. There is a collaborative advantage as students see the work of their peers. The teacher is well informed of the class comprehension and privy to detail beyond that possible with the usual CRS multiple choice or text response. A detailed and illustrated example of the Scan and Post technique is given in the action research section of this dissertation.

3. **Collaborative Data Analysis** – This combines the spreadsheet of the Quick Write technique with an instant graphing function. Experimental data collected by students, either individually or in groups, is entered into the cells of a spreadsheet corresponding to their name or group identifier. As an illustration, a physical science instructor teaching the concept of density could break students into groups. Supplied with blocks, student’s input data concerning a given block’s volume and mass and whether or not it sunk in water. Data entered this way from the collection of groups or individual is then mapped on a common graph projected for the class and teacher to review (Figure 4).
Figure 4. Collaborative Data Plot of Mass/Volume Ratios Revealing a Clear Trend

The graph eventually reveals data patterns. Departures from the pattern are identified as outliers informing particular groups that their data should be reconsidered. Students observe that anything with a density above an apparent ratio will sink and an object with a density below the level will float. In this way, students learn through a collective process of induction as opposed to direct instruction or isolated group activity. This type of data collection exposes students to a more characteristic method with which career research scientists work.
Traditional Formative Assessment

To add specificity to what is meant by continuous formative assessment, it is of use to illustrate in juxtaposition a few of the more popular traditional methods of formative assessment and the limitations that exclude them from the class of CFA. More common traditional methods of formative assessment include: the art of questioning, one minute essays, one-to-one student conferences, white boards and frequent quizzes. Because answers are given aloud, the art of questioning is most often performed in a fashion such that all students are not required to present a response to a given question. It would be impractical to have all students in a large class answering at once or in succession. Hence, it lacks accountability. The art of questioning is also distinguished from CFA techniques in that a permanent record of student responses is not kept.

One minute essays that ask the students to respond to one or two questions are often performed on student-supplied 3” by 5” cards. In this way, they do provide a permanent record. They could be performed in the moment and as often as the teacher chooses. They hold every student accountable as each student is expected to submit a completed card. However, they don’t provide the collective experience of students being exposed to each other’s responses. Students are not able to gage their answers with their answers submitted by their peers.

One-to-one student conferences provide the student and teacher a window into the student’s progress and provide the teacher with deeper knowledge of the student’s cognition with respect to course learning outcomes. A permanent record of such conferences is possible in the form of audio recordings. The accountability level of a one-to-one conference is in direct relation to the number of students the teacher is able to see.
over a short period of time. However, it would again be impractical to run student-teacher conferences regularly throughout a given class session. As with the one-minute essays, they lack the collective and collaborative features of CFA.

A TFA technique that can be done in the moment, has a strong component of accountability, and is somewhat collective is white boards. Each student displays their response to instructor questions by writing their answer on a white board and then holding up the white boards for the teacher’s review. The process can be collective especially if students are sitting in a circle and can see each other’s responses. However, white boards do not provide for a permanent record unless student responses are photographed.

Frequent quizzes represent a TFA technique that provides accountability, a permanent record, but lacks the collective/collaborative aspect of CFA. They could conceivably be issued in the moment but need to be graded. Hence feedback to the student is delayed.

TFA methods also may employ various forms of technology. For example, the art of questioning is often done with the aid of CRSs such as clickers. However, if the CRS requires pre-written questions, they cannot be used continuously or in-the-moment. Delivery of portfolios and feedback delivered by the teacher is often done over the internet. Again, in this instance, the cycle of student submitted work and the teacher’s response is less than continuous.

Both TFA and CFA methods of formative assessment provide both the student and instructor regular feedback such that the student can correct their misunderstandings and the instructor can adjust their teaching. The defining characteristics for classification
of formative assessment as CFA are those given in the Venn Diagram (Figure 2): collective display of student work, accountability, in-the-moment assessment and the permanent record of learning.

**Survey Questions**

Question details are based on the Next Generation Science Standards (NGSS) *Dimension 1* standards and ask the student-teacher subjects to reflect in two categories; as students and as teachers. It is of interest to know the subject’s previous experience with formative assessment as both a student and a teacher. Do they recall the benefits of formative assessment they experienced as a student? What were those benefits and to what extent as teachers do they expose their students to that type of learning? To what degree are they open to new technologies in the classroom? Of particular interest were the subject’s opinions on effectiveness of the cloud-based technologies they have been exposed to over the course of the semester. Have they been able to employ them in their own teaching settings? What have been the difficulties? What have been the advantages? More detail on the survey instrument is given in the methodology chapter.

**Theoretical/Conceptual Framework**

The theoretical framework for this study is derived from the existing literature supporting the effectiveness of formative assessment in general. Further, this study attempts to determine value the CFA strategy has on the quality of STEM education, as defined by *Dimension 1* of the NGSS, and along learning parameters of motivation, engagement, metacognition, accountability and collaboration. CFA techniques promote a shift in the paradigm of STEM education towards student-centered learning (Herr, Rivas, Chang, Tippens, Vandergon, d'Alessio, & Nguyen-Graff, 2014). In the teaching model
supported by CFA methods, engagement, motivation, collaboration and accountability are key features in student learning. This stimulates the students to a state of metacognition such that they consider their own thinking.
Chapter 2: Literature Review

This literature review looks at improving graduation success with a focus on ways to reduce the gatekeeping properties of courses in Science, Technology, Engineering and Mathematics (STEM). A theme of urgency to address the issue is expressed in the current national concern regarding the shortage of STEM graduates (Chang, Eagan & Hurtado, 2010; Drew, 2011). In addition, students of any major entering post-secondary education are shown to be underprepared in mathematics (NCES, 2006, 2009). This discussion leads to possible solutions used in the classroom to address these concerns. The dialogue narrows to one particularly effective classroom technique towards STEM success found in the literature; that of formative assessment (Herr, Holzer, Martin, Esterle & Sparks, 1995; Hewitt & Seymour, 1997; Lee, Feldman & Beatty, 2012; Gogus, 2013). Additional process themes follow as traditional and technical formative assessment techniques are reviewed. Ultimately a new form of formative assessment that has yet to be developed in the literature is identified; that which employs cloud-based technologies and can be executed in a more spontaneous and continuous formative assessment. It is found that this kind of cloud-based formative assessment is perceived by teachers experienced in its use to be effective in promoting student performance. Student performance is defined using the science and engineering practices specified in Dimension 1 of the Next Generation Science Standards. This investigation is believed to be significant to the problem statement in that better formative assessment may lead to better student performance, thereby promoting student retention and graduation rates in STEM fields.

Through the study of the existing literature, the derivation of additional paths of interest will materialize. Further questions will be raised: Are we addressing the issue of
low transfer rates to our best ability? What are alternative ways to address remediation in schools? Are science, technology, engineering and math (STEM) courses hopelessly destined to continue as courses that impede student success? In addition to these questions, certain conclusions synthesized from the collected literature can suggest further action designed to improve chances of meeting the goals set forth by the National Math and Science Initiative (NMSI, 2012) and the Next Generation Science Standards (NGSS, 2013).

Sources

The significance of online databases in the compilation of this review cannot be overstated. Primary search engines used were Google Scholar, EBSCO Information Services, ERIC, and Academic Search Elite. Further references given in articles were searched directly with the CSUN Oviatt Library online search page, and where articles were not available at the Oviatt library, interlibrary loan was implemented.

Criteria used in the searches for pertinent literature most often included the terms education, formative assessment, technology, STEM, mathematics, remediation, self-efficacy and motivation with the addition of various sub-topics including gender, ethnicity, attitude, online, hybrid, among others.

Methodologies used in the Literature

Various research methods have been used to examine this topic. Fundamentally articles reviewed fell under categories of quantitative, qualitative, and mixed-methods. 

Qualitative Methodology: The qualitative articles reviewed included opinion pieces supported by pertinent literature, organizational reports and case studies as well as subject-interview based studies. Quantitative Methodology: Most of the studies were
quantitative. Such reviews used a variety of approaches including surveys on a stratified sample, longitudinal matched pair studies, and regression analysis. *Mixed-Method Methodology*: Mixed method articles employed strategies of both the quantitative and qualitative methodology.

As the use of cloud-based technologies in the classroom is in its initial stages, there is a dearth of literature regarding its use in the formative assessment of STEM classrooms. Where such peer-reviewed journal articles were of limited availability, peer-reviewed conference papers were sought. Several reports were also found but included in this review sparingly.

**Urgency**

Science, Technology, Engineering, and Math (STEM) requirements at four-year institutions are a top national concern (Chen & Weko, 2009, NMSI, para. 1, n.d.). A 2010 study using National Student Clearinghouse figures reports that less than thirty percent of the 2004 cohort of students starting a STEM major graduated in that major (Chang, 2010). Carnevale and Rose (2010) estimate that by the year 2025, the U.S. will need an excess of 20 million college-educated workers. “A clear trend has emerged: The United States is losing ground in postsecondary education relative to our competitors” (Carnevale & Rose, 2010, p. 60). In the emerging global market, it is to our great national benefit to improve the aptitudes of our students in the universal language of mathematics. Unfortunately, students are leaving U.S. high schools underprepared to meet the mathematics requirements of the nation’s four-year institutions (RPGCCC, 2005). Technical and engineering jobs are going unfilled due to a lack of graduates in these fields (Boggs, 2011: Dice, 2010). A study published by employment agency Dice
Holdings, Inc., (2010), found that, in recent years, technology unemployment averaged less than half the nationwide joblessness. One issue is that students are not persisting in STEM majors. A sample of 12,000 students from cohorts of U.S. freshmen entering American universities as STEM majors between 1996 and 2001, showed forty-seven percent switching to non-STEM majors or leaving college altogether within six years (Chen & Weko, 2009).

The National Center for Public Policy and Higher Education (2010) noted that an average of nearly sixty percent of freshmen college students need remediation in English or mathematics. This average need for remediation climbs with a given institution’s level of enrollment access. The report refers to this problem as the Readiness Gap (Figure 5) (Shulock, & Callan, 2010).

A recent EdSource report (2011) investigated consistency in the relationship between California Standardized Tests (CST) and California Community College (CCC) learning objectives and standards. The comparison of the English material in CCC placement testing and CST was found in fair alignment in all four rubric categories. This was not the case in the relationship between CCC mathematics placement testing and CST. In a similar study on the alignment of CST to college math placement tests, Brown & Niemi (2007) note that, “Some mathematics topics covered by the placement exams are simply not addressed by the augmented CST.” The authors suggest that the way to mend the disconnect would be to make it known earlier in a student’s post-elementary school program what is expected in terms of math requirements at the CCCs.

At the post-secondary level, the transfer rate from a California Community College (CCC) to any four-year institution hovers around forty-one percent (CCCCO,
Hence, nearly sixty percent of students enrolling in the California Community College system are not moving on to a four-year institution. Those who do advance to a four-year institution are doing so at a delayed rate and taking three and more years to finish the two year program (Melguizo, Hagedorn, & Cypers, 2008). Better than seventy percent of CCC students are found to be deficient in eighth grade level remedial math courses such as beginning and intermediate algebra (RPGCCC, 2005). It is clear that better articulation agreements between California high schools and their regional community colleges need to be established.

**Figure 5. The Readiness Gap by College Access Level**

Implications

There is a broader importance to the focus on math and science as a gatekeeper to college success. Any course of study that hinders college graduation rates stands in the way of the larger national focus on learning accountability. The U.S. job market has emerged from blue-collar labor demands to expanding needs for high-tech skills. This has been an area of national concern for decades. Multi-national human resource consulting firm ManpowerGroup Inc. (2013) reports that the pipeline of technology and engineering qualified applicants has not kept pace with the growing demand for such skills in the global job market. In 1983, the National Commission on Excellence in Education in their letter to the American people lamented the failure of an educational system that has put our nation at risk noting that, “If an unfriendly foreign power had attempted to impose on America the mediocre educational performance that exists today, we might well have viewed it as an act of war” (NCEE, 1983). In several illustrations throughout the letter, lack of quantitative literacy is mentioned as a component in the diminishing quality of the U.S. education system.

STEM related employment is increasing overseas at a much greater rate than it is in the U.S. In “Rising Above The Gathering Storm” a report generated by the National Academy of Sciences (Augustine, 2005), it is noted:

Today, Americans are feeling the gradual and subtle effects of globalization that challenge the economic and strategic leadership that the United States has enjoyed since World War II. A substantial portion of our workforce finds itself in direct competition for jobs with lower-wage workers around the globe, and leading-edge scientific and engineering work is being accomplished in many parts of the world.
Thanks to globalization, driven by modern communications and other advances, workers in virtually every sector must now face competitors who live just a mouse-click away in Ireland, Finland, China, India, or dozens of other nations whose economies are growing. (p.27)

This trend was also covered by a National Science Board (2012) study on science and engineering labor indicators. It reports that research and development employment abroad for U.S. based multinational corporations (MNC) increased from sixteen percent in 2004 to twenty-seven percent in 2009. This is more startling when the growth rate is considered:

The 2009 data on MNC R&D employment abroad show a markedly different trend after 2004 from the trend in the preceding decade. About eighty-five percent of MNC R&D employment growth occurred abroad. Whereas employment abroad nearly doubled, domestic employment during the same period grew by less than five percent. (NSB, 2012, pp. 59-60)

On a positive note, the U.S. STEM-related employment has been on a steady increase. However, in the global arena it falls short of China and South Korea (NSF, 2014). The employment trend in the U.S. in recent years has increasingly moved from jobs dedicated to the production and sale of commodities to jobs concentrating on innovation (Freeman, 2006; Shaffer & Gee, 2005). The National Science Foundation (NSF, 2014) confirms that science and engineering occupations increased in the years between 2006 and 2012. This was in contrast to the shrinking U.S. workforce overall. In the same report, the NSF states that, “Employed college graduates with a highest degree in science and engineering (S&E) earn more than those with non-S&E degrees. Moreover, within each broad degree
field (S&E and non-S&E), those employed in S&E occupations earn more than those in non-S&E occupations” (p. 3-5). The foundation further indicates a growing demand for science and engineering majors noting that unemployment rates for those graduates are lower than the aggregate of college graduates and significantly lower than the collective labor force. The numbers are particularly noteworthy when in 2010 the national unemployment rate was reported to be nine percent while at the same time only four percent of science and engineering graduates were unemployed (NSF, 2014). As promising as these reports are, the growth in innovation-related jobs experienced in the U.S. continues to lag behind that of China and South Korea, “Among countries with large numbers of researchers - defined as workers engaged in the creation and development of new knowledge, products, and processes - growth has been most rapid since the mid-1990s in China and South Korea” (p. 3-6).

**Cost Issues**

While fees for post-secondary education are rising nominally, surrounding costs are rising much faster than inflation. Housing, textbooks, medical care have all gone up at least twice as fast as the nation’s inflation rate and state grants are not matching the pace. In addition, community college students are less inclined to apply for financial aid (Frankle & Zumeta, p. vii, 2007). These are the more apparent costs.

Less obvious are the costs incurred by a college or university student needing remediation. In addition to standard tuition and housing costs, to truly calculate the cost of attending a community college for example, one needs to include the extended time a student spends taking non-transferable courses. This leads to delayed graduation or transfer and time away from meaningful employment. Most often, these non-transferable
courses are non-credit bearing remedial math courses. Such is the thesis of *Remedial/Developmental Education and the Cost of Community College Transfer: A Los Angeles County Sample* (Melguizo, Hagedorn, & Cypers, 2008). In their study, the authors further inform the reader that such time-factored costs go up as we consider students from lower-income backgrounds where substandard K-12 education is more likely to occur. They emphasize their study differs from existing literature in that their study data is culled from transcripts and tested actual costs as a function of various levels of remedial needs.

The cost and gatekeeping implications of STEM courses necessitate the exploration of solutions. Formative assessment is given thoughtful and detailed consideration in this application. The following is a review of current and enduring literature on formative assessment, its variations and applications.

**Formative Assessment**

Reviewing nearly 200 sources on the effect of formative assessment on self-regulated learning, Ian Clark (2011) delineated formative assessment into formative, synchronous, and internal elements and observed that, “Each aspect has a powerful influence over the development of the metacognitive functioning and the self-efficacy required for individuals to make progress in their mastery of self-regulated learning strategies” (p. 2). His study maps a continuum from formative assessment through student learning autonomy (Clark, 2011). An abundance of literature focused on assessment and evidence-based learning is currently available and has been motivated by the national push towards a “culture of assessment” across all educational institutions (Popham, 2008; Weiner, 2009). A preponderance of this literature has focused on
summative assessments in the form of standardized testing, course finals and portfolios (Herr et al, 2014). More regular assessments regularly performed during lesson delivery that inform the teacher of adjustments to be made to improve knowledge and subject cognizance are known as Formative Assessments (Black & Wiliam, 1998; Popham, 2008). The immediacy of such teaching modifications is what makes formative assessment ‘formative’ (Herr et al, 2014; Shepard, 2005).

Assessment in the STEM classroom has traditionally been a summative process taking place following a number of class lectures. This type of assessment uncovers deficiencies in student learning weeks after the student’s understanding is initially breached. This makes it difficult for the student to catch up. More frequent assessment of student learning has its advantages in providing the student with timely feedback on progress and informing the teacher what adjustments to the teaching should be made (Black & Wiliam, 1998). Such frequent assessments are termed formative and have been practiced in a great variety of ways.

It is well researched that formative assessment can improve student learning success. Black & Wiliam’s (1998) often cited literature review of relevant formative assessment writings, Inside the Black Box, Raising Standards Through Classroom Assessment, surveyed twenty-one articles. Where their 1998 publication was a general accounting of formative assessment studies, a more recent study by the same authors is narrower in focus yet references more than seventy formative assessment articles. Classifying formative assessment’s inherent, unpredictable and real-time revelatory processes as “moments of contingency”, Black & Wiliam (2009) further define “synchronous contingency” as that which allows an instructor to make teaching
modifications in real-time. Asynchronous formative assessment is characterized by the delayed evaluation of student learning usually through grading processes (Black & Wiliam, 2009).

The use of formative assessment in promoting independent student learning was the subject of one 2006 study. English teachers were all shown to highly value the promotion of student learning autonomy. However, the approaches towards that goal differed. The authors suggest that the four criteria for which formative assessment was initiated - questioning, feedback, sharing and self-assessment - should be revisited as teachers individual modes of delivery affect the metacognitive higher organization of ideas and the ability for students to develop independent learning skills (Drummond, 2006).

Articles dealing with formative assessment in the STEM classroom are not as widely available as those dealing with the topic as applied in other disciplines. An exception comes in the work of Eugenia Peterson and M. Vali Siadat (2009) at Richard J. Daley College in Chicago. In a two-year longitudinal, quantitative study, hypotheses regarding the effectiveness of formative assessment in elementary algebra courses at the college were tested. The formative assessment in this case took the form of “frequent, cumulative, time-restricted, multiple choice quizzes with immediate constructive feedback.” The test group was given formative assessment. The control group was assessed traditionally with chapter tests. Noteworthy benefit to formative assessment was revealed in the summative assessments. On mid-terms, test-group students scored an overage of four percent above the control group. This advantage increased to seven
percent on the final exams. The improvement was found to be statistically significant well beyond the ninety-nine percent confidence level (Peterson & Vali Siadat, 2009).

Page Keeley (2008) details several formative assessment techniques for science and math classes in her book *Science formative assessment: 75 practical strategies for linking assessment, instruction, and learning*. In a related article, she notes the value of formative assessment in promoting reflection, transfer of knowledge, evaluation of ideas, new thinking and conceptual understanding. The collection of these attributes guide student learning towards the objective of metacognition (Keeley, 2013).

There are many types of formative assessment including regular quizzes, one minute essays, the art of questioning, and technology-based assessments such as clickers and on-line quizzes. New techniques of both traditional and technology assisted formative assessment are developed regularly. What follows is an overview of some of the studies regarding these various methods.

**Types of Formative Assessment and Their Effectiveness**

In this section, formative assessment is reviewed in two classes, traditional and technological. Traditional formative assessment (TFA) refers to that which is used to formatively assess student learning and includes; the art of questioning, hand signals - to measure levels of self-reported understanding, choral responses - students are invited to respond simultaneously to teacher-posed questions, think-pair-share - teachers assess student understanding as student groups share with the class, exit cards - students submit questions or answers as they leave class, self-assessments - students check their own understanding by working problems or answering questions in class and quizzes - teachers pose questions to test student understanding (Fluckiger, Vigil, Pasco, &
Danielson, 2010; Jahan, Shaikh, Norrish, Siddqi, & Qasim, 2013; Stull, Majerich, Bernacki, Jansen, Varnum, & Ducette, 2011; Youssef, 2012). All of these techniques have proven valuable in traditional classroom settings. However, the formative values of TFA techniques could be improved. For example, frequent quizzes are not ideal in the interest of evaluation in the moment as they are often graded after class. White boards gather and report data in real time and make every student accountable to answer but are not ideal for peer learning applications, lack any advantage of anonymity in student response, and only collect data temporarily. This is not ideal for recording a history of student progress. Exit cards can be reviewed quickly and constitute a record of learning but are not easily made visible to the class for peer review. Think-pair-share exercises can be evaluated quickly, hold students accountable, involve peer collaboration but whole-class collection of data is limited to discussion in the sharing stage (Herr, Rivas, Chang, Tippens, Vandergon, d'Alessio, & Nguyen-Graff, 2014).

CFA has been found to provide more collective, recordable and real-time assessment that gathers input from all students (Herr, Rivas, Chang, Tippens, Vandergon, d'Alessio, & Nguyen-Graff, 2014). Technological means of formative assessment can be traced back to audience response system developed in the early 1970s (Simmons, 1988). Electronic feedback from audiences was performed in the 60’s for marketing purposes in the entertainment industry (Bugeja, 2008; Collins, 2008), the use of Audience Response Systems (ARS) for formative assessment finds its initiation with the Consensor audience response system developed for businesses by Bill Simmons in the early ‘70’s (Broderick, 2009; Bugeja, 2008; Simmons, 1988). With the Consensor apparatus, employees at meetings were able to electronically respond anonymously to questions and survey items.
The responses would appear as red, yellow or green flashing lights on a receiver thus providing valuable, largely unbiased, information to managers and employers. This alleviated the problem of groupthink where employee responses where influenced by what they thought the employer wanted to here and led to better participation and more authentic consensus in decision making (Broderick, 2009; Simmons 1988).

The value of the audience response systems in the educational setting was also being realized in the early 70’s. By 1985 an ARS known as Classtalk was produced by a retired NASA engineer and educational researchers with funding from the National Science Foundation (Beatty, 2004; Broderick, 2009). Currently there exists a plethora of such ARSs known to education as “classroom” or “audience” response systems. They employ the use of dedicated devices known as “clickers” and more recently less dedicated devices such as smart phone apps both of which communicate audience input to a classroom computer from which the teacher can monitor the student responses (Kay & LeSage, 2009). Students inputted their responses to instructor posed questions. The instructor then received immediate statistics on student performance on true-false, multiple-choice and short-answer questions. Through the collection of individual student responses and the display of polling results, teachers could aggregate class levels of understanding of key points in the lecture. In addition, data was gathered and can be used in future reporting and analysis (Herr, Rivas, Chang, Tippens, Vandergon, d'Alessio, & Nguyen-Graff, 2014).

Presently a variety of classroom response systems (CRS’s) are available for educational applications. They include clicker devices designed for classroom use, classroom computer networks, and applications available on smartphones that can collect
and extrapolate student responses to teacher formulated questions (Kay & LeSage, 2009). The mode of input for CRS’s is more often limited to the selection of lettered multiple choices, though some such as the smartphone applications are capable of text input. One of the great advantages of CRS’s is whole class response with associated accountability. This inherent feature significantly reduces instances of students assuming positions of non-engagement. Student accountability to the teacher is therefore increased. In addition, the adoptable component of responder anonymity greatly reduces students’ apprehensions of possibly offering wrong or embarrassing answers. Hence, students feel freer to respond without the dreaded repercussions of potential disapproval from the teacher or classmates. The immediacy of complete class response affords the instructor the ability to address that response with expediency (Kaleta, 2007). Several studies have illustrated the effectiveness of CRS’s (Beatty & Gerace, 2009; Bennett & Cunningham, 2009; Buchanan, 2001; Chevalier, 2013; Gok, 2011; Peat & Franklin, 2002).

Classroom response systems now have the ability to instantly display collective poll results from student-selected answers to multiple-choice, true-false and short-answer queries. The results are quickly displayed to the instructor with various calculated formats of descriptive statistics. This gives the teacher a window into the class’ level of understanding over discussed topics and lessons. The value of the collective data is not restricted to teacher’s usage in formative assessment. In cases where the collected data is shown to the whole class, students also gain. They observe how their peers are thinking and are exposed to alternate viewpoints and methods of addressing topics, problems and phenomena discussed in STEM classrooms (Herr, Rivas, Chang, Tippens, Vandergon, d’Alessio, & Nguyen-Graff, 2014). A large control study of 3500 students was conducted.
over the 2004 and 2005 fall semesters at the University of Wisconsin. Both students and faculty reported that classes employing CRS’s significantly improved engagement, participation, interaction and student learning (Joosten & Kaleta, 2007). A number of additional studies have also confirmed the effectiveness of CRS’s in student engagement, learning accountability and cognition (Herr et al., 2014; Beatty & Gerace, 2009; Bennett & Cunningham, 2009; Buchanan, 2001; Chevalier, 2013; Gok, 2011; Katella 2007; Peat & Franklin, 2002).

As successful as CRS’s can be in improving the ability of instructors to formally assess, classroom response systems have conventionally lacked in two areas. The first is the limitation to spontaneous usage. In traditional formative assessment, a teacher may freely test levels of student understanding at will with the art of questioning or the use of white boards, for example. Use of CRS’s is often not performed in the moment. Many CRS’s require the instructor to design appropriate questions prior to presenting a lesson. If the teacher thinks of further paths of inquiry into students’ levels of understanding, the CRS’s requirements for predesigned questions are less amenable to unplanned paths of inquiry (Herr, Rivas, Chang, Tippens, Vandergon, d'Alessio, & Nguyen-Graff, 2014).

The second area where CRS’s may leave instructors wanting, a STEM instructor in particular, is in the format of input. CRS’s have conventionally accepted input only in the form of student-selected responses to prefabricated multiple choice or true/false questions. As a result, they render information that is not particularly revealing of student thinking processes. Newer smartphone-based CRS’s, such as Socrative and Poll Everywhere, do allow for text input. Yet STEM courses are very often concerned with symbolic and illustrative communication that would disclose more advanced stages of
learning. For example, a teacher giving a lesson in projectile motion may want to see if the class can illustrate the effect of given input variables on that motion. Symbolic notation used in STEM courses, such as various cyphers representing derivatives and integration, are not available on CRS keyboards. More recently developed CRS’s including tablet-oriented programs such as the *Nearpod* application and the *Ink Survey* format developed at Colorado’s School of the Mines, do an excellent job of accepting symbolic and illustrative input on a tablet screen (Gawlik & Treacy, 2013; Kowalski, 2013a). As with more restrictive CRS’s, real-time processing of student responses is the primary feature of Nearpod and Ink Survey. Instructors see in an instant which concepts students are retaining and on which topics they have misconceptions. The advantage is the deeper insight afforded by the more descriptive input possibilities. A recent study supported that substantial learning gains were realized by students in science courses when formative assessments were performed with the use of the advanced tablet based CRS called *Ink Survey* (Kowalski, 2013a).

**Cloud technologies.** Many of the technologically based formative assessment studies are limited to handheld devices that communicate student responses to instructor initiated multiple choice prompts or very limited text entries (Buchanin, 2001, Peat & Franklin, 2002, Bennett & Cunningham, 2009). When internet technologies are employed, the formative assessment comes in the form of instructor emails or peer to peer chat boards (Crossouard & Pryor, 2007). In a 2009 study, researchers at Wake Forest University, N.C., found that “handheld computers ease the data-gathering process because of their unobtrusiveness and ease the aggregation of data because of their technological features” (Bennett & Cunningham, 2009, p. 100). The authors noted that
users of handheld computers struggled with the equipment’s limited input capabilities, “Hardware problems often made the technology burdensome rather than helpful” (Bennett & Cunningham, 2009, p. 101).

In lamenting an absence of pedagogical direction in articles promoting various Classroom Response System (CRS) technologies, authors Beatty & Gerace in the *Journal of Science Education and Technology* include an important recommendation, “The first step is for practitioners, evaluators and evangelists of CRS-based instruction to articulate their pedagogical perspectives and methods in as much detail as possible” (2009, p. 148). Before engaging the latest popular instructional tool, a teacher should determine how the device will most effectively be introduced in the instruction. For example, such devices have been used to motivate discussion as a method of formative assessment, to improve classroom engagement, and to promote deeper levels of learning among other uses.

Formative assessment has been held to be particularly effective with lower-performing students and has therefore been encouraged of teachers new to the profession who generally have a disproportionately large percentage of lower performing students (Athanases, & Achinstein, 2003). Other means of delivering formative assessment, such as the online quizzes packaged with textbooks, have been shown to be positively correlated with student mastery of course material (Green et al., 2007; Hoon et al., 2010).

A cautionary view to online education is given in *Education as Commodity: The Ideology of Online Education and Distance Learning* (Cremer, D., 2001). The article is concerned with online education in general and the concept of students being reduced to “markers of quantitative productivity rather than qualitative assessment.” In the online arena, the professor is recast in a role that is not so much the creative and influential motivator of
knowledge but more a facilitator of a marketable educational consumer product. Cremer concedes that some success for the online instruction format has occurred at the basic math level. He tempers this admission with an insight that advanced levels of abstract thinking skills may not be as well served by a distance learning and electronic form of delivery.

The importance of formative assessment is not just in the student learning. There is an iterative nature to formative assessment. It is a “joint productive activity” (Ash & Levitt, 2003). Students assemble and interpret knowledge and present their understanding to the instructor. The instructor then adjusts his teaching to enrich the learning and meet immediate student needs. The focus on formative assessment and how it can achieve various qualities of learning was examined in an article by two professors of education at the University of Sussex (Torrance & Pryor, 2001). The authors champion the use of action research in the development of best practices in formative assessment. The authors coin two terms; convergent assessment – “if the learner knows, understands or can do a predetermined thing,” and divergent assessment which attempts to ascertain the learner’s deeper comprehension of a particular topic (i.e. surface vs. deep learning). In the course of their study, teacher researchers collaborated through a series of shared video recordings and 17 meetings and were enlightened on their own classroom formative assessment practices. Action research was found to be an essential professional development tool:

For teachers to be able to develop new approaches to formative assessment and relate them to different theories of learning, they must be able to investigate and
reflect upon their own classroom practices—particularly the way they question and give feedback to students.

Through action research, the teachers in the study saw more clearly the effects of their student questioning and discovered many areas in which it was lacking and could be improved.

**Distance Learning and Formative Assessment.** Distance learning is a growing field in all disciplines (Moller, Foshay & Huett, 2008). Classes conducted online tend to lend themselves to assessment techniques that stimulate enhanced engagement and learner-centered activities (Gikandi, 2011). In particular, students receive immediate feedback from online tutorials and quizzes and this has been shown to improve student enthusiasm and results (Chen 2009; Hatziapostolou, 2010; van Gog, 2010). As experienced with traditional graded feedback of homework assignments, computer marked learning projects have also been found to keep students on task (Jordan, 2009).

When pre-lecture online quizzes were performed outside of class to a group of 112 undergraduate education students, the degree of improvement was found to have a strong and positive correlation to the number of pre-quizzes taken. One advantage noted in assessment performed remotely was that it was not obtrusive to the class (Stull, Majerich, Bernacki, Jansen, Varnum, & Ducette, 2011). Support showing positive correlation between quiz frequency and outcomes was also found in a large general chemistry class setting at an unnamed urban university (Stull, Varnum, Ducette & Schiller, 2011, p. 35).

The direct relationship indicating the greater number of quizzes taken resulted in greater summative test scores was in contrast to a study performed at Richard J. Dailey
College. In a matched pairs study conducted by Peterson & Siadat (2009), regular in-class quizzes were given to an elementary algebra class and were observed at different paces, 13 per semester vs. 26 per semester. The results failed to indicate any development of significance in learning achievements among the students. Regardless of the potential effect granted by the pace of online quizzes, a conceivable disadvantage is the teacher would not be experiencing the efficacy of their teaching in real-time when they would be more inclined to adjust their instruction. *Formative assessment* generally implies that instruction is dynamic such that the teacher can change their instruction as a function of student input (Black & Wiliam, 1998; Herr, Rivas, Chang, Tippens, Vandergon, d'Alessio, & Nguyen-Graff, 2014).

Further studies have considered the advantages of verbal feedback. Because the written word can be more easily misinterpreted and a verbal approach can be given a more personal feel (Morra & Asis 2009). Extending this concept to distance learning, one study explored the use of audio emails to provide regular formative feedback to a cohort of business management students (Macgregor et al., 2011). In the quantitative study, it was found that students receiving written feedback performed slightly better on the summative assessments but not significantly.

Peer-to-peer collaboration in the educational setting has been advanced through the application of social networking (Blue & Tirotta, 2011). Metacognition is further supported as students reflect on their learning through the use of blogs (Herr et al., 2014; Olofsson, Lindberg, Hauge & Trond, 2011). As with CRS’s, student anonymity in delivering feedback online effectively provides instructors with useful knowledge beneficial in promoting operative changes to their teaching (Berridge, Penny & Wells,
The variety of online methods of student-learning feedback delivery can be advantageous to both faculty and students (Herr, Rivas, Chang, Tippens, Vandergon, d'Alessio, & Nguyen-Graff, 2014).

Cloud Technologies and Formative Assessment

A 2011 report listed possibilities in social networking and cloud computing towards peer to peer collaboration and formative assessment (Blue & Tirotta, 2011). The article, whose subjects were pre-service teachers at a mid-size northeastern U.S. private university, identified challenges the teachers found during the classroom implementation of various web resources. Issues included teacher reluctance to participate due to privacy issues where social networking was involved and functional difficulties when internet connections were breached. The learning curve in the use of the technologies was also an issue.

At Colorado’s School of the Mines (CSM) math, biology and physics students have been using electronic tablets (ET) to present their answers to a teacher’s prompt. ETs allow students to give their answers in all manners of pencil-to-paper response; symbolic, graphic, or written word. Subsequently, a CSM created program called “Ink Survey” projects the student-response ET images to a screen at the front of the class. One great advantage to this process is that very little additional class-preparation is necessary. Where clickers inherently require a teacher to fashion carefully considered multiple choice questions prior to each class session and restrict students to multiple choice answers, the tablet-to-screen technology of the Ink Survey allows teachers to conjure and deliver learning-assessing questions in the normal flow of a class discussion. The student’s thinking processes are now projected for immediate teacher evaluation.
The employment of such technologies brings formative assessment to the level of “hyper-clickers”.

While the CSM model employed a programmer to write and maintain the Ink Survey software, useful cloud-based technologies need add no technical costs to the classroom. Free web resources immediately applicable to STEM classrooms include Google products such as Google-Docs, Google-Sites, media programs such as Picasa Web and (Apple’s equivalent), and social networking services such as Twitter and Yahoo Groups. There is a cost to the training of employees in the use of web resources. This would likely include release time for fulltime faculty and stipends for adjunct faculty.

Angelo Fernando, a marketing and communications strategist in Mesa, AZ, 2008, reported on a few educators who used various web resources such as Innertoob, Twitter and YouTube in classroom instruction. At the time, he noted that of these modes of instruction, “the age of engagement is still in its infancy” (Fernando, 2008). Four years have passed since Mr. Fernando’s opine. Most of what literature that does exist on cloud computing and formative assessment comes in the form of reports. Judging from the current deficiency in peer reviewed journal articles on the topic; it appears that the implementation of cloud technologies in the classroom is off to a slow start.

CSUN’s Computer Supported Collaborative Science (CSCS) team are currently educating student teachers on the use of a vast array of available cloud based technologies applicable to science and non-science (Herr, Rivas, Foley, Vandergon, d'Alessio, Simila, Nguyen-Graff, & Postma, 2012). With the intent to meet the Next Generation Science Standards (NGSS, 2012) in mind, the CSCS team presented a peer reviewed conference paper entitled, “Using Collaborative Web-Based Documents to
Instantly Collect and Analyze Whole-Class Data” (Herr, Rivas, Foley, Vandergon & Simila, 2011). This paper outlined the advantages of web-based technologies that engage students and promote the philosophy that science is a collaborative process best implemented in a peer reviewed setting. The conference workshop involved the audience of educators in a hands-on demonstration where they analyzed data gathered and conveyed by their colleagues in real time using web-based resources. They call this real time analysis, Continuous Formative Assessment (CFA).

**Continuous Formative Assessment.** CFA methods allow an instructor to draw together student-collected data from a class of any size and evaluate the information in real-time. The techniques are flexible enough as to have applicability in face-to-face, and synchronous or asynchronous online formats. Students are engaged at the same time the instructor is able to monitor their learning progress. Adjustments to instruction are made in the moment to direct and redirect the learning. Peer-to-peer learning is achieved as students are exposed to and evaluate the collective response data they generate. Through this practice, students experience and develop an appreciation for the importance of the collaborative professional environment in which career research scientists operate (Herr, Rivas, Chang, Tippens, Vandergon, d'Alessio, & Nguyen-Graff, 2014).

Traditional and technologically based formative assessments are not mutually exclusive partitions. For example, the intended properties of student assessment through traditional hand-raising and quizzing methods are shared in CFA methods using hi-tech clickers and electronic tablets. The collaboration of an entire physics class experiment using cloud technologies has self-similarity to small group labs performed in a traditional
physics class. The difference is in the value of the larger data sets and the peer to peer visibility achieved in the CFA format.
Chapter 3: Methodology

The initial impetus behind this dissertation was to find effective methods to address the disproportionately high attrition rates of students majoring in STEM fields. In researching these methods, identification of various reasons that students leave these majors was uncovered. The focus of this study was then narrowed to two of these reasons; motivation and student’s sense of self-efficacy. In exploring ways to engage students who lack motivation and who have low self-efficacy, formative assessment has historically been found to be particularly effective in bringing students to higher achievement (Black & Wiliam, 1998). It was also anticipated that improved treatments of formative assessment would improve retention of students who were not majoring in math or science and realized a gate-keeping effect with STEM courses.

It was beyond the feasibility of this study to determine the extent of correlation between formative assessment and retention of students taking STEM courses. However, because a positive correlation between formative assessment, motivation and self-efficacy was evident in the literature (Cauley & McMillan, 2010; Hewitt & Seymour, 1997), and in turn a link between self-efficacy and retention is also established in the literature (Onwuegbuzie, 2000; Street, 2010), a transitive link between formative assessment and a potential decrease in the attrition of STEM majors was considered a reasonable assumption. As observed by Vincent Tinto (1993), “the more at-risk students come to develop mastery over previously difficult material, the more positive they become in their view of what is possible in the future. This, in turn, leads to heightened likelihood of future success” (p. 183).
A lack of literature regarding promising new technological methods that afford more continuous formative assessment (CFA) was noted. Ideally, control and test groups would be employed in a longitudinal study approach to uncover the most effective formative assessment approaches. However, this study had time and resource constraints that disallowed the consideration of a longitudinal approach. It was determined to be of considerable value to reflect on teacher reports on the quality of teaching and learning observed in their classrooms before and after they employed the use of CFA. This suggested a within subjects ex-post facto design.

This research therefore focused on the influence that CFA strategies had upon the quality of teaching and learning in STEM classes. The influence of CFA on the quality of teaching in STEM classes was observed, through interviewing and surveying teachers who had taught the same subject matter both with and without CFA. The quality of STEM learning was measured with respect to the degree that students engaged in the scientific and engineering practices listed in Dimension 1 of the Next Generation Science Standards (NGSS).

In particular, the investigation compared traditional types of formative assessment with CFA methods in an attempt to discern which was perceived by teachers experienced in the use of both as most beneficial to student learning. The study examined teacher training and dispositions in the various uses and methods of formative assessment. The effects of interest included; engagement, motivation, student accountability, metacognition and collaborative benefits.
Basic Research Concepts

Currently, much of the assessment in STEM fields is done in a summative fashion. Students assessed this way may have lost their understanding of the course material weeks before the assessment is given. In such instances, the teacher is usually unaware of this breach in student learning until the summative assessment is graded. Using more regular assessment of students as part of the learning process is called formative assessment and has been shown to improve retention of course content, deeper understanding of concepts and motivation in the learning (Peterson & Siadat, 2009).

This project will benefit society in identifying the educational benefits of formative assessment as it applies to STEM fields. In addition, this study focuses on a new form of assessment developed by a team of science teachers at California State University Northridge called Continuous Formative Assessment (CFA). The study compares the CFA methods of formative assessment with traditional formative assessment.

In exacting a definition of what is meant by “educational benefits” in the context of this dissertation, the desired learning skills in Dimension 1 of the Next Generation Science Standards were imposed. Dimension 1 with related sample survey questions in the context of this study is given here:

**Dimension 1 Scientific and Engineering Practices (NAP, 2012)**

- 1. Asking questions and defining problems
  - How frequently do you ask your own questions in class as a student (by hand, verbal)?
  - How are problems defined in class?
    - Teacher describes problems; problems come from student input
    - Student originated “why questions”
Research Questions

The focus of this research has developed from an initial quest to improve graduation rates at the post-secondary level to questions that focus on ways of improving retention in STEM courses. The concentration on formative assessment is developed in the literature review as a best practice for improving student retention in STEM courses. The research questions for this study are:

(1) What are the perceived influences of continuous formative assessment using collaborative cloud-based technologies (CFA) on student engagement, motivation, collaboration, metacognition, and accountability in STEM classrooms?

(2) What are the implications of CFA for reaching the learning goals expressed in Dimension 1 of the Next Generation Science Standards (NGSS).

Protocol Design

The research method will employ a within-subjects ex-post facto design. This method of research is conducted in the absence of control and test groups and looks at the experiences of subjects as they consider whether a given treatment was responsible for a
specified relationship. The ex-post facto component refers in this study to the subject’s reflection of experiences after a treatment (Shavelson, 1988, p. 27). The within-subjects characteristic is realized by the fact that perceptual data will be gathered from observations of the same subjects, as opposed to matched pairs of subjects (Shavelson, 1988, pp. 463 – 467). The treatment in this case is the learning of CFA by both pre-service and in-service student-teachers in education classes held at California State University Northridge.

Most of the data was gathered from teacher perceptions. Instead of looking at test scores, the focus was on a quantifiable response from teachers. This was a similar process to that done in epidemiological studies where self-reports and perceptions in subject’s minds can ferret out trends, patterns and differences that would be difficult to ascertain from regular test scores. An example would be the study of dispositions towards nuclear energy before and after the Chernobyl disaster (Verplanken, 1989). In education, an ex-post facto research design would be applicable in a case where lower high school grades are realized from students coming from one town vs. students arriving from another town. The ex-post facto design would then explore possible causes for the grade differences such as social economic status, cultural attitudes towards education, and ethnicity (Diem, 2002). An example of within subjects combined with ex-post facto design would be that of the comparison of Advanced Placement programs with Honors programs at the same high school. The subjects would be teachers who have taught in both programs and can offer insights as to which program was most effective on a given list of parameters (Herr, 1993).
In the interest of triangulating the information found in this research, three fundamental approaches were taken. They were:

- Classroom Observations
- Purposeful Interviews
- Surveys

The classroom observations took place in three locations. The first was in the spring of 2013 at the Colorado School of the Mines (CSM) in Golden Colorado where I observed a number of classes in mathematics and the sciences. In the same Colorado visit, another observation of a class in microbiology was performed at Red Rocks Community College. Finally, a semester of courses in the use of CFA was observed at California State University Northridge.

Interviews were taken on three fronts. One was with eleven teachers experienced in middle school and high school applications of CFA techniques. A second series of interviews was taken with focus groups of teachers newly exposed to CFA methods. Additional interviews were held with three California Science Project (CSP) professors who taught CFA techniques with varying years of experience both in classrooms and in professional development retreats. One of the professors, Dr. Norm Herr, served as the chair of the committee in charge of the review of this dissertation.

The survey process consisted of pilot and final query instruments. I took an additional investigative measure in the form of action research where I applied CFA techniques in my own mathematics classes. Each of these approaches is further detailed below.
Subjects

The subjects for this study were purposefully sampled. As such they were deliberately sought for their elevated propensity to inform this research of a central phenomenon (Creswell, 2012); that of the perceived effectiveness of CFA techniques. The subjects included (1) pre-service middle and high school science teachers receiving training in CFA in various teacher credential courses taught in CSUN’s Department of Education, (2) in-service middle and high school science teachers receiving training in CFA as part of a masters of education program at CSUN, (3) in-service science teachers engaged in workshops in which they are introduced to CFA, (4) science professors who implement CFA in university courses, (5) my students at Woodbury University as I instructed mathematics classes with the aid CFA techniques.

Subjects were observed in the courses and workshop given in Table 2.

Table 2

Description of the subjects and the classes in which they were observed

<table>
<thead>
<tr>
<th>Semester</th>
<th>Location</th>
<th>Class</th>
<th>Students</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 2013</td>
<td>CSUN</td>
<td>SED 514: Computers in Instruction</td>
<td>Pre-service teachers from all disciplines</td>
<td>20</td>
</tr>
<tr>
<td>Spring 2013</td>
<td>CSUN</td>
<td>SED 646 - Science methods course</td>
<td>Masters program in-service science teachers</td>
<td>20</td>
</tr>
<tr>
<td>Spring 2013</td>
<td>Colorado School of Mines (CSM)</td>
<td>Physics I</td>
<td>STEM majors</td>
<td>120</td>
</tr>
<tr>
<td>Spring 2013</td>
<td>Colorado School of Mines (CSM)</td>
<td>Honors Calculus III</td>
<td>STEM majors</td>
<td>120</td>
</tr>
<tr>
<td>Spring 2013</td>
<td>Colorado School of Mines (CSM)</td>
<td>Chemical Engineering Process Dynamics</td>
<td>STEM majors</td>
<td>70</td>
</tr>
<tr>
<td>Spring 2013</td>
<td>Red Rocks Community College (RRCC)</td>
<td>General College Biology</td>
<td>STEM and Non-STEM majors</td>
<td>30</td>
</tr>
</tbody>
</table>
Observations

CSUN courses were held on Wednesdays. SED 514 ran from 4PM to 6:50PM. SED 646 ran from 7PM to 9:50PM. Over the fifteen-week semester, I attended all sessions of each course with few exceptions. Observational data of these classes was recorded as narrative notes. The notes were then coded under major themes of formative assessment, engagement and motivation, metacognition, accountability and collaboration.

I attended one each of the courses held CSM and RRCC with the exception of Physics I where I observed two class meetings held by two different teachers. Observational data of these classes was also recorded as narrative notes which were also coded under the major themes of formative assessment, engagement and motivation, metacognition, accountability and collaboration.

Interviews

The interview process followed a blend of ethnographic and phenomenological forms. Ethnographically, I was interested in the subjects’ views about CFA methods, how they characterized their students’ cognitions following the application of CFA, and what they understood as the value of implementing CFA techniques. The phenomenological aspect of the interviews took form as I deciphered meaning from the teaching stories told by the subjects. I encouraged such stories from a deliberately naïve point of view (Rossman & Rallis, 2003). Further interviewing occurred through my participation with students during classroom exercises and experiments. This latter variety of interview was not retrieved as audio recordings but was recorded on paper in timely recollection.

One-on-one interviews. One-on-one interviews were arranged in a formal setting. Fourteen subjects participated in the individual interviews. They were all conducted in
various offices and classrooms on the CSUN campus. I arrived at the interviews prepared with a list of questions regarding each subject’s experiences in teaching, administration, formative assessment, technology and pedagogy (Appendix A). The interviews lasted 30 to 45 minutes and were recorded in a digital audio format. The interviews were then rendered as text by the Rev.com transcription service. I coded the interviews under major themes of formative assessment, engagement and motivation, metacognition, accountability and collaboration.

**Focus group interviews.** The focus groups were decidedly less formal in order to encourage spontaneity and scaffolding of responses. Each group consisted of six to eight in-service middle and high school teachers who were attending a one week long summer professional development institute. The institute was offered through the coordinated efforts of Project Grad Los Angeles (PGLA) and the CSUN branch of the California Science Project (CSP). The same list of questions prepared for the singular interviews was deemed appropriate for the focus groups (Appendix A). The time for the focus group interviews was expanded to one hour. However, fewer questions were covered. This was due to the informal setting, several interviewees, and the encouragement of tangential assessment-related discussions. However, the key issues with regards to each groups’ experiences in teaching, administration, formative assessment, technology and pedagogy were covered. The focus group interviews were recorded in a digital audio format as well and similarly put to text by the by Rev.com transcription service.

**Action Research**

To achieve a personal and operational understanding of the potential virtues of CFA methods, I sought to apply the techniques in my own teaching. Due to limitations
of available technology on the campus of his employment, I opted to use smartphone technology and the Scan and Post technique (Herr & Tippens, 2013), a CFA method suggested by Dr. Herr. With this technique, it was required that most students have a smartphone on which they upload two free apps: Camscanner – that has the ability to create pdf and jpeg scans of illustrations on paper through the use of the smartphone camera; and Dropbox, a popular cloud storage app. Additional technology used was a tablet PC and an overhead projector fitted in the classroom.

The subjects of the action research were architecture majors attending a required trigonometry course. As the opportunities arose throughout the fall 2013 semester, I would ask students to apply recently discussed concepts to various applications such as exercises in trigonometric functions on the unit circle and graphing of vector applications. The students would render their understanding on paper as would be done in a standard classroom. The students were then directed to scan their work and post it to a Dropbox I created and dated for that day’s session. The student-contributed images were then displayed in matrix form on the projector screen as the front of the class. This allowed all students and myself to review the work of the entire class.

**Surveys**

**Pilot Study.** Pilot surveys were prepared using the free Google Docs program (see Appendix B). Most of the survey items were questions that Dr. Norm Herr, a founding member of the CSCS team and my dissertation chair, used in his previous semesters surveys that adapted well to this study. It was administered to two classes at the beginning of the fall semester of 2012. The pilot survey process allowed me to determine what questioning approaches would be most effective, whether further survey items
would be desired, and provided initial benchmark data on instructors’ experiences with formative assessment.

As the focus of the dissertation topic developed, additional questions were added to the final survey in two additional sections (Appendix C); (1) CFA: Effects on engagement, motivation and accountability, (2) CFA as it relates to Dimension 1 of the NGSS. These questions would not have been applicable to the pre-survey as the students had not yet been exposed to the CFA teaching methods. In the first section, the questions ask the subjects to reflect on values such as potential effects of CFA in terms of student learning, mental engagement, and accountability for the learning. The second section asks students to compare the CFA methods of formative assessment to traditional methods they experienced in the past both as teachers and as students.

**Final survey instrument.** The final survey measurements were collected using the Google Docs survey instrument and given in the final week of the 2013 spring semester. Likert scale reporting and open ended questions made up the body of the survey. The open ended survey questions used the same coding scheme as the one on one and focus group interviews. Dedoose.com was engaged in this section of coding (Appendix D).

The refined final survey was given in the final week of the 2013 spring semester. Among the subject characteristics collected in both pre and final surveys were logistical questions concerning the STEM discipline in which the subjects taught, how long they had been teaching, and their general affinity with technology in the classroom. The remainder and bulk of each survey queried the teacher’s perceptions of CFA and its efficacy in assessing student learning, and enlightening the teacher on student cognitive
levels with respect to course material. All subjects were asked to reflect on CFA
techniques they experienced as students in CSUN’s educational department. Subjects who
were in-service teachers were asked questions concerning their perceived effectiveness of
CFA in the instances they used the techniques. Subjects in the pre-service category were
asked to forecast what they felt would be the effectiveness of particular CFA techniques
over various categories. In the closing section of the final survey, all subjects were asked
questions on their intended future use of CFA techniques.

**Ethical Considerations**

CSUN and Woodbury University IRB approval was required and was obtained
prior to any data collection. The subjects in this study were informed that they were being
observed in the classroom setting. They were reminded of this fact by the course
instructor at regular intervals throughout the semester.

Names were collected on the pre and post surveys as a means of determining who
had taken a survey and who needed to take a survey. The processing and analysis of
survey data was not tied to names.

Name data collected and given in this project report was stated anonymously or
names have been changed. The data will be held for approximately 3 years following
completion of the study and then will be destroyed.

**Summary**

Through this dissertation’s investigation of teacher dispositions on various
methods of formative assessment in STEM classrooms in synthesis with the current
literature on the topic and its positive effects on classrooms of several disciplines, it is
expected that a noteworthy and effective means of STEM student retention will develop.
The objective of the CFA classroom is to supercharge the engagement of students and teachers in concert. This paper will attempt to determine whether such improvements are realized with CFA. While there are a number of reports on CFA and related methods of teaching, critical research papers specifically examining these methods are scarce. This dissertation aspires to help remedy this deficiency in the literature.
Chapter 4: Results and Findings

The research questions for this study are;

1. What are the perceived influences of continuous formative assessment using collaborative cloud-based technologies (CFA) on student engagement, motivation, collaboration, metacognition, and accountability in STEM classrooms?

2. What are the implications of CFA for reaching the learning goals expressed in Dimension 1 of the Next Generation Science Standards?

Triangulation of data collection methods was employed in the interest of cross validation. The approaches included:

   - Interview with Dr. Norm Herr
   - Classroom Observations
   - Pre-Survey
   - Individual Interviews
   - Focus Group Interviews
   - Action Research
   - Final Survey

Through these approaches, a developed account of the potential benefits and conceivable difficulties with the use of cloud technologies towards the goal of improved formative assessment was revealed.

I. Interview with Dr. Norm Herr

   In the interview with Dr. Norm Herr, a time line assembled around the development of CFA and the impetus that led to its formation was revealed. He discussed
the shift in pedagogy supported by CFA. The interview culminated in a discussion of the significant effect CFA has had on his own teaching.

As reported by Dr. Herr, from the start of the new millennium, professors with the School of Education at CSUN were involved with a professional development project funded by the California State Department of Education and the No Child Left Behind Act of 2001. Known as the California Science Project, it endeavored to train teachers in implementation of the California Science Content Standards which were adopted by the California State Board of Education in October, 1998 (Bruton, Ong, & Geeting, 2003).

The pedagogy behind the CSP professional development project, as explained by Dr. Herr, was to reinforce teachers’ knowledge of their science and to enrich the methods of teaching their subject. Dr. Herr described CSP’s “immersion units where the students would engage in very lengthy laboratory-based activities that would hopefully give them a deep understanding of specific contents related to California State Content Standards in Science.” In one such activity, students performed an inductive experiment developed by the University of Wisconsin. Students would record numeric observations of various objects submerged in water. Plotting graphs with axes representing volume and mass, they would converge on a ratio of volume and mass values required for floatation. The collaborative process required students to stack graph transparencies on an overhead projector. Ultimately the result would reveal itself though the process of stacking transparencies was cumbersome and inaccurate:

First of all, they all had to align their graphs very, very carefully. Any slight movement of one transparency on top of the other would result in some potentially un-interpretable data. Then, when you put 10 transparencies on top of
each other it became relatively opaque, so it became much more difficult to see the patterns.

Dr. Herr found a more workable solution in 2009 with the application of the Google Docs online spreadsheet. It had capabilities that allowed for simultaneous input from multiple users with results posted and plotted on a single document. Outliers and flawed data were easy to identify in the accurate plots made. His colleagues agreed this was a more ideal format in which to conduct such collaborative exercises. As such, a new pedagogy was initiated that emphasized cognitive development over the teaching of content. Dr. Herr’s enthusiasm for this collaborative use of cloud technologies led him to present on the advantages of the method at the Hawaii International Conference on Education in January of 2010.

Other professors involved with CSUN science education and professional development were also enthusiastic about the use of cloud technologies in teaching. The group had originally assembled primarily on the basis of CSP funding but began to convene around the concept of collective learning. They named themselves the Computer Supported Collaborative Science (CSCS) team and began to seek additional funding towards the goal of expanding professional development opportunities for K-12 science teachers and the reach of the new pedagogy. Through these efforts, they have been awarded funding from Hewlett-Packard.

The team continued their two-week summer teacher training sessions in partnership with the Los Angeles Unified School District. These sessions followed an academy model where Los Angeles area teachers were exposed to the team’s computer based collaborative formative assessment techniques. In 2013, Project Grad L.A.
(PGLA), an independent non-profit Los Angeles-based organization committed to promoting successful paths to college for disadvantaged inner-city middle school students, provided an additional partnership with the CSCS team. The organization delivered L.A. area middle school students to a *Summer Academic Enrichment Program* run by the CSCS team. The team provided teachers for the workshops. The teachers then had the opportunity to practice techniques of CSCS and CFA with the PGLA students in a variety of classes given themes such as *Imagineering, Science Olympia,* and *Myth Busters.*

In the last part of the interview, Dr. Herr spoke of the significant change that the methods of CSCS and CFA have had on his teaching. In particular, he noted the more accurate window the methods provided into student thinking. He juxtaposed this feature with previously taught traditional methods:

In a traditional classroom, you do some kind of guided practice before the students go home. At home, they may or may not have a good understanding of what's going on, and if they don't have a good understanding, they may mis-learn something, and then they have to unlearn it the next day. The beauty of continuous formative assessment was that I could always see ahead of time, before they were dismissed, that they understand a particular concept, and if they didn't, I could modify either the homework assignment or my instructional plan to remedy that issue before it got out of control.

He further elaborated that spreadsheet activities would reveal a more detailed actuality of the understanding of the whole of the class. On occasion, this could have a *blindsiding effect* where his assumptions of students’ understanding were well out of alignment with
student responses. He noted the value this had in improving the results of his summative assessments, “Students tended to do better and actually reported a greater interest in learning.” This he attributed to greater accountability of the student towards their peers, to the teacher and to themselves, in the CFA classroom experience.

Dr. Herr explained that, because CFA techniques make possible complete student input, the art of questioning becomes more deliberate and useful, “I'm picking students based upon their contributions rather than upon when they raise their hand.” Observing a host of student answers, he is able to select the most appropriate responses to aid the learning process. In addition, he notes that the quality of student contributions has increased; the students are more contemplative before submitting their responses for full classroom exposure and permanent record.

In discussing another advantage in terms of teaching focus, Dr. Herr noted, “I don't waste my time talking about concepts that they already understand, but rather build upon those concepts to ensure greater understanding.” This would suggest that CFA promotes efficiency in instruction made possible by the clearer picture of student comprehension that is a proposed feature of CFA methods.

**Summary**

Throughout Dr. Herr’s personal history with formative assessment, he clearly developed a strong belief in the use of cloud-based technologies in collaborative and formative review of student learning and teacher growth. In his assessment, the technologies were not simply a new tool in the delivery of required course material but a powerful instrument in the transformation of pedagogy. The impact on teaching
perceived by Dr. Herr was such that he felt his instructive abilities would be at a
disadvantage without the availability of CFA technologies.

II. Classroom Observations

With the focus on this research being the perceptions of teachers exposed to the
use of new technologies, it was of interest to observe how the teachers were introduced to
CFA. With Dr. Herr’s permission, observations were made of his technology in education
courses. I also sought to determine the degree to which the teachers were exposed to CFA
technologies: Were the teachers fully immersed in hands-on training of the technologies
or simply introduced to suggested uses for technology in the classroom? What did their
classes say about the influence of technology on pedagogy? In addition, it was of value to
know who the teachers were: What were their backgrounds in terms of teaching
experience and courses taught? Why did they attend these courses?

In several of the observed sessions, I was engaged as a participating student. What
follows is a description of the students pertaining to the background questions given
above. Also described are common class procedures. Some of the highlighted activities
from the many classroom observations are given where appropriate.

Typical class structure. The classroom where all of Dr. Herr’s classes took
place was a standard traditional rectangular room, 35 feet by 45 feet. It was given modern
technological improvements; entering the classroom required a key code held by the
instructor and computers were available at every seat. In the classroom, two rows of
tables were set up perpendicular to the front wall. Seven swivel chairs down each row
faced the individual computer terminals. Dr. Herr was at the front of the classroom with a
computer of his own on a raised podium. His computer projected to a standard pull-down
screen. There was also a smart board directly behind the teacher. The room was well air conditioned. There were “no eating, no drinking signs” on the walls. Locked 6’ tall cabinets lined the back wall and one side wall. The chairs are moderately comfortable with hydraulic height adjustment, flexible backs, rolling on a linoleum floor.

The students for SED 514, *Computers in Instruction*, were pre-service teachers of various disciplines fulfilling a credential-program course requirement. These students were generally in their early to mid-twenties. For SED 619, an internet resources course for science teachers that focused largely on website development, the students were in-service science teachers in a master’s program. The students in SED 646, *Computers in Math and Science Teaching*, were also in-service teachers in a master’s program in secondary science education. The students for these latter two courses were for the most part in their late twenty’s to mid-thirty’s. There was one student that could be considered to be in her late 40’s in one of the classes. The cohorts for all three courses were largely white with two or three Asian and Hispanic students in each of the classes. A couple of the students had their own lap tops. There was a sign language interpreter communicating with one or two of the students in each of the different courses.

**Formative Assessment.** As the semester proceeded, it became apparent that Dr. Herr’s courses were concerned with how to teach science as much as they were with educational technologies. The emphasis was on how the computers could best be used to promote student learning. Dr. Herr often mentioned the value of various technologies towards formatively assessing student learning. In the first class session, Dr. Herr orientated the class on the uses of the web. Among the many technologies and applications used in the courses related to formative assessment were: electronic Quick
Writes to collect student answers to spontaneous topic-related questions, Google Docs for collaborative student response, Google Moderator to collect student questions, and a smartphone app called CamScanner – a document scanner that could capture student illustrative renderings for instructor review in a process called *Scan and Post*.

In each session of each course, Dr. Herr had the students log on to a program called Blackboard Collaborate. It was a University-paid web conferencing program that provides a synchronous virtual classroom environment. He mentioned that a free system was available called Google Hangouts but allowed access for only ten students at a time. He would then turn on a recording feature. In each class, the students joined the virtual class session from their computers.

In one particular class session, the teachers were instructed to type their names into a white space visualized on their computer screens. The collection of names showed up at various places on the screen and the results were projected on the classroom projector screen. The teachers were able to click on their own names, move them around and change their size. There was also a *chat box* associated with the program. Dr. Herr asked the class, “What’s your favorite subject?” The teachers were clicking on the hand-raise button in the Collaborate program in order to be called on. This was the virtual equivalent to raising their hands in a face-to-face classroom. Dr. Herr explained:

This is a form of formative assessment. It is a major topic in this class. Typically we talk of summative assessment. You’re often way too late when you get a summative assessment. A five-week progress report is too late. It’s hard for a student to dig themselves out of a hole after five weeks. There are many different
forms of formative assessment. How many of you know about formative assessment?

A few teachers raised their virtual ‘hands’. “Raising hands is a pretty weak formative assessment. It doesn’t tell you much about what the student really knows about the question asked.” At this point, Dr. Herr experienced a glitch in the hand raising function – he had difficulty figuring out how to put the students hands down. He eventually asked the students to lower their hands in the program. He explained that he didn’t get to test all the program functions until he had a class.

As a Quick Write exercise, Dr. Herr asked the class to give their individual definition of formative assessment in reference to what they had seen in this class so far. One student wrote “Continually assessing the students understanding.” One student noted that it would allow a teacher to modify teaching. He then asked, “Based upon the answers seen in column D (where the answers were given), would you go on to the next topic at this point?” The next answer started to fill up with student answers of ‘no’, a few begin to answer yes and the tide began to turn. There was an influence issue apparent in this line of questioning. Dr. Herr instructed, “Once you get used to this, it will be second nature and you will be using it all the time.” Dr. Herr then turned the text-color in the spreadsheet to white so that student answers would not be visible and therefore not bias other student answers.

Some of the teachers were having difficulty logging on. “If your login is not working, don’t worry, we’ll get it straightened out.” [OC: Some teachers helped their classmates]. Dr. Herr announced that he was going to record this lesson for future viewing on Moodle. The recording is done on through a link on the top of the Blackboard.
The class will be using a lot of Google resources. It has replaced the 500 dollars in software that was previously required of students to buy for this course. Dr. Herr talked about collecting student papers on Dropbox. The noted advantage was that as a teacher, you don’t lose papers. With each of the CFA processes Dr. Herr employed, it was clear that the assessment of student learning during the learning was taking place.

While this activity was performed by the teachers on computers located in the classroom, it was apparent that the class would be able to join the session from any location as long as they had a computer and internet connection. Indeed, there was one instance during the semester where Dr. Herr conducted the class remotely from Toronto where he attended a conference. This incident provided me with an observation of how CFA could work in a distance learning format. About one third of the class attended virtually from their home computers. Two thirds came to use the computers in the usual classroom. I assisted in the classroom making sure Dr. Herr’s live remote feed operated properly. There were problems with audio feedback which were corrected when each student brought down their individual computer volumes. The only audio sent to speakers was that from the main podium. That solved the problem.

Dr. Herr did a few additional diagnostic exercises to make sure the hand raising function and Quick Write were working so that he could formatively assess students. He then led the class in a graphics exercise using website called Biodidac. He saves selected images to Dropbox folder. They have a little trouble with joining this graphics session where they can put up their own graphics. The class was then instructed on a Quick Write to determine which browser and computer platforms were working and which weren’t. Dr. Herr noted that this was an example of NGSS problem solving and the class solved
the problem collaboratively looking for patterns in the whole-class data collected and interpreted using the cloud-based Quick Write.

The first Quick Write for this session asked, “What is contextual learning?” Answers given included; learning every day or within a context of time, what happened this last week – what happened this week. The class then discussed current science events such as the skydiver who broke the sound barrier on the anniversary of Chuck Yeager’s breaking of sound barrier and the docking of the space shuttle Endeavor at the L.A. Museum of Natural History. All this provided talking point opportunities.

**Engagement and motivation.** Examples of engaging CFA-related classroom exercises the teachers could apply in their own classes made up a great portion of all three courses observed. One such exercise was that of a periodic table construction application. Virtual Paint chips in a Google doc were organized to form the table projected to the screen in the front of the classroom. Four elements were not represented. Students needed to identify which were missing as they arranged the paint chips on the document. Paired teams determined the best way to arrange the paint chips. They worked on their independent computers but the document was common for each pair. What I observed was not a class passively listening to a lecture. They were engaged in a learning activity. I’ve observed the same level of engagement in many traditional classrooms. What was different in this example was the ease with which the collaborative process of the whole-class contribution to one periodic-table was realized.

Each class ran once a week for three hours. Initially, teachers would be scattered about the seats. The class would be mostly full within the first five minutes. A few teachers would arrive late. The class would be completely full ten minutes into the
session. At the start of class, Dr. Herr would instruct the students to turn their computers on and, if they had an unattended computer next to them, to turn that on as well in preparation for the late arrivers. The students would open a specific page with appropriate links for the given course. Dr. Herr would post a Quick Write general question such as, *what causes seasons* or *which high school course is the best predictor of high school success?* Teachers would type their entries and their responses would be projected on the screen in the front of class. This process served to collect roll and engage teachers in the first of the class discussions. Being engaged in this course was important. Participation was a significant twenty percent of their grade. Looking at the projected Quick Write spreadsheet, I observed most if not all classmates participating and entering responses to the initial *warm-up* questions. On the occasions where one or two teachers didn’t respond, it was due to delays in the starting-up of their computer terminals.

The meetings were hands-on sessions with several activities that kept the class engaged, providing examples of best uses for technology in the classroom. Such activities regularly included the afore mentioned Quick Writes, exposure to new website of educational interest, web site developing procedures and peer review. Details of activities are found in the following sections.

A discussion of Next Generation Standards was given in each of the observed courses. This was a whole-class discussion. In one class, teachers paired up at a computer terminal and reviewed an article on the Next Generation Science Standards. They highlighted concepts they thought were most important. Each team entered their ideas on the computer and displayed at the end of the exercise on a Quick Write spreadsheet projected to the class. Some of the concepts pulled from the article were “getting families
involved in students learning of science projects”. Another team came up with
“encouraging underrepresented student groups” Another team came up with, “real world
problems are motivating” as opposed to “why am I doing this?” There was now a reason
to learn this material. Relevancy will be much more important than it was in the past.
Another team came up with, “too many misconceptions”. The movie “Private Universe” -
that looked over the reasons for the seasons - was brought up by another student pair.
They mentioned how some folks think the elliptical orbit explains how summer occurs -
that is happens when we are closest to the sun. However, when we observe that the
southern hemisphere has summer when the northern hemisphere has winter, we have to
reject the elliptical orbit explanation. Students then commented on other teams posts.
These comments were posted to another column of the Quick Write spreadsheet.

The activities observed were, again, not that of a class receiving instruction
passively. The CFA activities observed clearly engaged the teachers in a process of
learning by doing.

**Collaboration.** Dr. Herr explained his classes were about the collaborative
process. Electronic media aided that process. He said, “You’re going to want to be able to
teach interactively. It’s a new paradigm that you’re going to need to know.” He added,
however, “Just bringing the internet into the classroom is not going to improve teaching
or learning. It can be quite detrimental. The web is the greatest source of information and
the greatest source of misinformation.”

In the SED 619 website development class, Dr. Herr set up a website that allowed
teachers to collaborate on its content and design. It was called a Wiki. Teachers in the
class were charged with recording various instructions to Wiki page. Dr. Herr said, “You
will be taking notes collaboratively. Each person will take a portion of the notes and post them to the Wiki. The course page has a class notes link. It is the wiki style of collecting notes.” The designation of specific tasks for the teachers followed during the regular flow of the class. One teacher was assigned to add instructions on how to create a web-page banner. Another teacher was given the task of recording the steps to creating links within a webpage.

In one class, Dr. Herr was able to involve a collaborative exercise as a “time-filler” during a period when a few students were having difficulty logging in. After directing the rest of the class to post their photos to a Picasa web page, Dr. Herr instructed the class to pair up and learn something about each other. They then entered those notes under the each other’s photo. The activity helped to build community. It was an ice breaker. Dr. Herr did another Quick Write to illustrate that on the fly, the technologies you can apply when you are underprepared. “You need to be prepared for when you’re not prepared”, he noted.

Dr. Herr then showed some videos previously created by students using a time-lapse photography app called SloPro® for smartphones. He put his smartphone on a smartphone tripod. A ball is put on a rail angled down to a block. The ball is filmed as it rolls into the block. He then posted the film on the classroom screen. The teachers were then assigned to make their own videos using the SloPro® app. The following week, the teachers shared videos they made in the classes they taught. They had the opportunity to mutually critique each other’s work. This exercise provided a formative assessment in the form of peer review. One showed an explosion experiment from a science class caused by correct carburetion of an alcohol with air. A teacher showed his student’s stop motion
which he posted on a YouTube. Dr. Herr noted that the YouTube had 43 views which indicated that the students have been sharing their work. This example showed the Lytic Cycle and was very entertaining. The smiles and laughter during the presentations were evidence that the teachers had fun with the exercise. Another teacher had his stop motion loaded in a Drop Box folder. A termite followed an ink pen because the drying chemical in the pen smells just like the termites pheromone. Another student shared one a video clip on line density at the DMV.

In a session of *Computers in Math and Science Teaching* (SED 646), I participated in an inductive reasoning exercise. The goal was to develop the equation for the period of a pendulum. First we needed to define what motion would represent the period of the pendulum. We then determined the variables that might affect the period of the pendulum. A list was generated on a Quick Write by the class. On the Quick Write list, students entered such variables as; length of the string, pivot point stability, the height and angle from which the pendulum is dropped, the release velocity of the pendulum, the mass of the pendulum and the environment (air resistance). To reduce the variables, the class agreed to keep some factors constant; the pivot point would be secured so it would not wobble as the pendulum swung, the release angle would be fixed at 45 degrees as it was deemed fairly easy to estimate, and to keep the release motion consistent, it was suggested the same person release the pendulum for each timed period. The number of swings the pendulum performed in a minute was counted by each team performing the experiment. Timing was done with stop-watch apps on the teachers’ smartphones. The pendulum exercise was collaborative within the individual groups and with the class at large as each group posted their collected data. Each laboratory group
contributed a few measurements to a common spreadsheet, and scatterplots developed illustrating that the period of the pendulum was independent of mass, but dependent on the square root of the length of the pendulum arm.

Perhaps the most collaborative exercise Dr. Herr employed was the whole-class review of the websites each teacher created in class. After each web-design activity in which the class engaged - such as the aforementioned creation of banners and insertion of video clips - each teacher’s work would be presented to the class for review. Over the weeks, improvements to each teacher’s website were evident. The teachers appeared to enjoy the exercise of displaying their work. There was a competitive spirit. The motivation appeared to develop from the extrinsic type whereby the teacher directs the students to complete a given assignment for a grade to the self-motivated intrinsic variety.

**Metacognition.** In another class session, Dr. Herr started a Google Moderator exercise. Most of the class was unfamiliar with Google Moderator. “Google moderator supports learner based inquiry as opposed to what the teacher thinks is an important question”, Dr. Herr explained. This appeared to be an effort to increase metacognitive awareness motivating the teachers to adopt the questioning of “what to do next” (Veenman, Van Hout-Wolters, Afflerbach, 2006). Students were to post one question concerning course content. Following their posting, they would vote on questions other students posted that they felt were of interest. After all questions and votes are submitted, the teacher could determine the questions shared by the greater portion of the class. The teacher could submit responses to questions on the Moderator and/or use the results to tailor further instruction.
In an effort to motivate inquiry learning in the master’s course in science education (SED 646), Dr. Herr developed a student activity with balloons they constructed out of tissue paper. A discussion of important variables observed in the previous weeks’ pilot experiment preceded the activity. Students learned that buoyant force needed to overcome gravitational force. This was the conclusion reached after the teachers made their observations. When being filled with hot air, the small balloons didn’t go anywhere but larger balloons started to rise. The ideal shape of the balloon in the pilot trials appeared to be spherical. This decreased the surface area to volume ratio. Through this process of inquiry learning some teachers realized that surface area related to force of gravity and volume related to force of buoyancy. Dr. Herr confirmed the relationship. Other variables of significance became apparent to the teachers during the inquiry learning process included the temperature differential, and the weight distribution. Following a preliminary discussion of these factors, the class went outside to test their balloon designs. One very large balloon was successful in clearing the top of the two story science building. Another balloon took off but didn’t clear the height of the science building. Another balloon burst into flames before it left the ground. Another large balloon was not able to contain enough hot air to rise at all.

An important point, Dr. Herr mentioned, was that learning by inquiry put the teacher in a facilitator role. However, it was not abdication of responsibility. It was guiding the learning. Dr. Herr noted that inquiry learning was time-consuming. Guidance was the key. Everything in the balloon experiment followed dimension 1 of NGSS standards. The challenge was going to be the assessment tool.
In an SED 619 class session, difficulties arose when students wanted to view a syllabus from another student's shared Dropbox. Dr. Herr was able to read it in a given browser but the class, using the same browser, wasn’t. Some opened the Dropbox folder in another browser with success. Dr. Herr made a point that this unintentional problem was solved by the class collaboratively – collaboration is the key. Dr. Herr said that he is not teaching science so much as he is teaching how to think, “We didn’t learn any science in solving our problem but we learned something more valuable – deeper knowledge of analyzing and interpreting.”

Some Quick Write exercises were dedicated to thinking processes. Dr. Herr’s questions would post such questions as, “If you want to debug a problem, how many variables should you change?” or “What is the scientific method?” All of our answers are projected on a screen as line items on the Quick Write spreadsheet. As we were writing our answers, we couldn’t see what others were writing because Dr. Herr had our text whited out.

In the terms of metacognition, most of what I observed in Dr. Herr’s class fit the model of metacognitive awareness. Dr. Herr would articulate the importance of encouraging the teachers to get their students to accept the questioning process as their own. “Make your own thinking explicit. How are we trying to solve this problem?” Dr. Herr was communicating his own thinking. He noted that novice learners learn by seeing the instructors thought processes. Expert learners are metacognitive. Dr. Herr feels PowerPoint has significant drawbacks in that no thought process or motivating of student engaging of students. Now if you’re a disciplined learner, you will use power point to engage students. He gave an example of how PowerPoint was not ideal for the teaching
of mathematics, “When solving a math problem you need to know the thought processes of what to do next; what are the questions you need to ask; students need to learn the questioning process that leads to a solution.” CFA techniques revealed new abilities in promoting student knowledge about their own thought processes.

Accountability. The Quick Write was the CFA technique Dr. Herr used most often in his course, employing it at least 7 or 8 times per class session. The Quick Write increased accountability in such a way that all classmates were engaged and required to contribute in a given class discussion. It allowed the whole class to type into the same documents simultaneously. On the Quick Write spread sheet projected to the class, Dr. Herr created columns in which his class of teacher entered the type of computer they had at home, the operating system, and the general course they taught. He then sorted the spread-sheet to collect the courses taught grouped together. There were about 11 biology teachers, 6 chemistry, 2 math teachers, and 2 physics teachers. He wanted each group to select an editor that would make weekly editorial comments on their groups’ progress. This would be done in a directory. This created accountability among classmates.

Dr. Herr noted that Quick Write had a revision history that would indicate which teacher did which task with color coding. “In this class you can run but you can’t hide” he said. By that he meant that their classwork was traceable as it was all done in the cloud. For example, he could always check attendance by looking at the dated Quick Write activity. In these observations, the promotion of accountability through the implementation of CFA methods was much improved over traditional methods.

Accountability in Dr. Herr’s class was evident in three forms. His Quick Writes included a roster of student names as the first column. When a teacher in the class didn’t
contribute a response to a given question, it was visible to Dr. Herr. He would state, “We’re waiting for Marty’s response” for example if I were the one not yet submitting a response. Such instances were not uncommon and were an example of accountability to the teacher.

Accountability to peers was often evident in the website creation exercises described above in the collaboration section. Teachers in the class were paired up as review editors of each other’s websites. Each week they were to write of the positive and problematic aspects of their partners websites as they were developed. I recall Dr. Herr posting these reviews in class. Initially, many reviews lacked constructive criticism with a tone of, “Your website looks great!” and little else written. He asked the class, “What do you think of this review?” The class responded noting that the review was without helpful value. The following week, the reviews were much more constructive.

The pride and care in the work the teachers brought to the website development assignments and the classroom experiments showed the pupils’ accountability to themselves. They knew these works were to be viewed by their classmates and this seemed to bring up the quality of work. As one teacher noted in the interviews, having work viewed by the class made the activities was more important them than having a letter grade issued to them by the teacher.

Summary

These classroom observations provided me with a more complete understanding of the depth and types of exposure to CFA teaching techniques the survey subjects received. An understanding of the overall direction of the courses developed as the semester advanced. In particular, it became evident that technology was not presented so
much as a new device for teaching but chiefly as a means to insure the promotion of an
improved pedagogy based on effective promotion of formative assessment,
metacognition, collaboration, accountability engagement and motivation. From the first
day of each of the three observed courses, the students were fully engrossed in the use of
CFA technologies. Students were instructed largely in a participatory manor and they
were receptive on the whole to each newly presented technique.

**Trip to Colorado School of Mines**

In researching technologies used in formative assessment, a compelling example
was found at the Colorado School of the Mines (CSM). Professors at CSM’s College of
Applied Science and Engineering developed a web assisted software called *Ink Survey*
that allowed for the real-time collection of student responses drawn on pen-enabled
mobile devices (Kowalski, V., Kowalski, S.E., Colling, T.J., Gutierrez Cuba, J.V.,
Gardner, T.Q., Greivel, G., Palou, E., Ruskell, T., 2013). I found a winter 2012 visit with
Ink Survey developers, Dr. Frank Kowalski and Dr. Susan Kowalski to be revelatory.
Graciously, they gave me access to several of the school’s classes run by various STEM
professors. The class sizes ranged from 30 to 120 students held in standard classrooms
and lecture halls respectively.

**Formative Assessment.** Students at CSM were developing a formative
assessment application that allowed for pen-input on any device through any browser.
This appeared to be an expansion on the Ink Survey but with a less proprietary platform.
In addition, Dr. Kowalski was working on a question-collecting application similar to
Google Moderator that could be used for very large classes and would process a more
flexible array of student input.
Of the classes observed, two professors employed the use of CRSs and another two professors used Ink Survey in their formative assessment practices. An example of the latter was a morning Chemical Engineering Process Dynamics class. At the start of class, students came to the front of class to get an iPad if they don’t already have one. This was a big classroom with a capacity of 70 students. The age range of the students was late teens to early 20’s.

A question handout was distributed. Students were to go over the questions and log into Ink Survey on their iPad’s. They were to submit the answers on their iPads. The questions were review questions. Some students paired up. The desks were standard individual classroom desks. Most students appeared to be working alone.

Two screens displayed a class journal at the front of the room. “When you have a question, raise your hand. Has anybody written down a transfer function?” No one responded. The professor went through some questioning to bring students to task. “How do you get K?” K was the gain variable. “It’s ultimate change in the output over ultimate change in the input. What is that going to be in a thermometer? It’s going to be one if your thermometer was worth anything!”

The professor went around the class answering individual student questions. Most students seemed to be on task. Occasional hands went up. Graphing calculators were being used by some students. One student told the teacher she was frustrated with the iPad. The professor told the student to go ahead and use paper. The professor then addressed the class and explained a first order transfer function. “You should know the first order response to a step change.” The teacher then wrote on the tablet and the work was projected on the screens. A Laplace transform was shown to the class.
After leading the class through the transfer function of the first problem, the professor continued to answer individual student questions. Most students were using paper as opposed to the iPad’s to do their work. After 15 minutes, the professor went over a second problem. This time she used the white board in front of the class. Many students were checking their work with the teacher’s work. “Any questions on this one?” She received no response. “Third one, there’s a trick, has anyone noticed the trick on the third one? On an exam, I might use this as a concept question such as ‘which of these thermometers has a higher heat capacity?’”

Forty minutes into the class session, very few students were using the iPads. The professor put out a request for some of the students to submit answers via the iPad. She requested of the other students, a one sentence email from students regarding their trouble with iPad.

The professor brought up a matrix of student names on a projector screen at the front of class. She then proceeded to open a blank page on the screen. “What was the mathematical model or ODE from which the equation was derived?” A minute later, two student responses appear on the screen. The teacher then asks the students if they don’t like to use the iPad to do the work. The responses indicate that the class generally agrees to the statement. They want to use paper and pencil and then show their final answers on the iPad. After class, the professor told me that she used ink survey much more successfully with the tablet PC.

The next day, an 11 AM Physics I class was visited. It was a large class with 150 students seated in a semi-circle. The space was a fairly modern lecture hall and was mostly full. “Today’s topic is Work”, announced the teacher. He started with a gravity
velocity question to which he requested a show of hands for the answer. The lecture was
given with the aid of PowerPoint slides. An image was projected on two large screens in
front of the class. The image was of an object on a ramp. Time, acceleration vectors
represented the kinematics. “Today”, the teacher said, “we’ll have an easier way to do
this.” The Students were taking notes with pencil and paper. One student had a laptop
out. The demographic was largely white and 60/40 male to female. The age range was
late teens to early 20’s.

This was a largely traditional lecture class with occasional choral response type
questioning. However, about twenty minutes into the class, the teacher asked, “What was
the work done on the baby by the normal force of the floor on the baby?” The students
had CRSs. Student response data to the question given was shown on the screen. Fifty-
one percent responded with zero. Two percent said less than zero. Forty-seven percent
responded greater than zero. This was only shown after all answers have been submitted.
One student explains their “greater than zero” response. The clicker response led to much
more engaged classroom discussion. The teacher led further discussion with several
questions that did not use the CRS.

This activity was followed by a second application of CRS-aided questioning that
again led to a very engaged discussion. One student defended his positive response as he
believed based on an argument concerning thermal energy. The teacher conceded to point
but said they weren’t yet at that point in the class and that thermal energies would be
discussed in the future. A return to traditional questioning was observed to by much less
engaging with only a few students answering teacher prompts.
A 3PM section of the same Physics I course was held in the same lecture hall and used the identical PowerPoint slides as the 11AM class. It soon became clear that the teaching of these courses was preplanned and designed by the Physics department in order to achieve uniform delivery of the course content. This was later confirmed by the professor. While the professors had different styles of delivery, one being more humorous than the other for example, the material taught was identical. This also applied to corresponding examples. The spontaneous choral response questions varied by professor but the CRS questions were identical. The observed effectiveness of the CRS questions was also similar. The second class was as responsive to the CRS questions and as engaged in the follow-up questioning as first observed class.

On the third and last day of my Golden Colorado visit, I attended Dr. Susan Kowalski’s General College Biology (BIO 111) class to observe her use of *Ink Survey*. This class was held at Red Rocks Community College (RRCC). As with Dr. Gardner’s class, Dr. Kowalski employed the use of tablets for student input in response to teacher prompted questions. As with CRSs, the student response could be submitted anonymously or not depending on the teacher’s assessment goals. It was an expansion on CRSs in that a larger variety of input was possible before each student response was reported to the teacher. In addition, the teacher received a view into the student’s thinking processes as the answers given via tablet were more detailed than the selection of a predefined multiple choice answer. With Ink Survey, learning prompts were executed more continuously and in-the-moment than they were with the CRS process I observed in the CSM Physics classes. In particular, prewritten multiple choice questions were not required with Ink Survey as they were with the CRSs.
After a period of traditional choral response questioning during the class session, Susan announced, “At this point I would like you to summarize the light reactions by what was used and produced using Ink Survey.” Susan further directed the students to summarize with a plot on the ROYGBIV spectrum (x axis) of chlorophyll absorbance levels. The students begin entering their responses on their tablets. After the students submitted their work, Susan invited me up to view the computer on her desk which received and displayed the student input. She was not projecting the student responses to the rest of the class. In the results of the first pass, only one of the student’s graphs was correct. As a result of this information, she modified her instruction to further clarify the light reaction concepts. After her further discussion, she initiated another round of the Ink Survey process. On the second pass, she had one hundred percent correct responses. In this class, iPads were the hardware used for Ink Survey with two exceptions where students are using tablet pcs.

She noted to me that, with the Ink Survey process and its illustrative input capabilities, she gained a lot more information about student thoughts than she would via the CRS process. The data she received from the Ink Survey informed her further traditional questioning of the class, “What else do we have going on here?” Another student, “What does the wavelength do?” “That’s the light energy.” The class proceeded in a fairly engaging discussion that involved most of the students. It was apparent there was a lot of material to cover. Susan applied the Ink Survey twice in this three hour class as an appropriate activity to break up the straight lecture format.
Summary

My visit to CSM and RRCC provided further insight in the uses of CFA as applied in larger classroom settings and in classes attended by university-level STEM majors. When professors of large lecture-hall classes applied CFA with the use of a classroom response system, engagement visibly increased. The professors also received data on student understanding of the material.

In the smaller class held at RRCC, art of questioning with choral response was the predominant formative assessment technique used. It was appropriate in the smaller setting. However, Dr. Kowalski’s insight into student cognition was greatly enhanced when she employed the Ink Survey.

III. Pre-survey

Data from pre-class surveys conducted by Dr. Herr for three of his CSUN Spring 2012 courses were made available to me (see Appendix B). The courses were SED 514 – Computers in Instruction attended by pre-service teachers of various majors enrolled in a credential program, SED 525 – Methods of Teaching Science by pre-service STEM teachers enrolled in a credential program, and SED 619 – The Sourcebook for Teaching Science a master’s level course in teaching strategies for STEM teachers that introduces a great deal of technology resources. The pre-survey data was of value in two areas. Firstly, it served as a pilot illustration towards the development of questions and techniques that would be used in the final survey conducted for this research. As such, I was able to determine what questions were not yet answered and needed to be included on the post-survey. Secondly, survey questions concerning the subjects’ previous experience with formative assessment helped to establish baseline information for the general population.
of subjects surveyed following exposure to CFA classes and professional development workshops.

The pre-survey was created by Dr. Herr and was administered at the beginning of the first day of class. Giving the survey in class achieved maximum participation; eighty-four students took the survey. The respondents were prompted with logistical questions concerning subjects taught and years of experience, scaled questions concerning respondent’s confidence levels with respect to technology in the classroom, and free response questions such as their knowledge of formative assessment (See Appendix B).

A review of the pre-survey data provided me with the opportunity to review what would be considered important information, what was missing, and what could be removed in the final research survey. For example, accountability as a potential feature of CFA was not included on the pre-survey and therefore was added to the final survey. Direct questions on the effectiveness of CFA were determined to be of significance and thus added to the final survey as well. Not considered vital to this research were questions on the pre-survey concerning beliefs about specific values of science teaching. Such questions were designed to promote classroom discussion in Dr. Herr’s class and were not of direct value to this research.

**Teaching Experience of Subjects.** Thirty-nine percent of responders had their credential in biology though only a quarter were teaching the subject. The second largest share on the credential list was for Foundations of Science at twenty-six percent. Just over half of the responders had a credential in two subjects. The rest of the responders had credentials in chemistry, geoscience and physics in descending order of distribution. Earth Science, Life Science, Physical Science, Chemistry teachers were represented in
the response data in a range between ten to fifteen percent each. Integrated science for non-college track students was taught by less than five percent and Physics was taught by marginally more than five percent of respondents.

**Confidence levels.** Of interest to this research were the respondents’ confidence levels in areas of formative assessment, collaboration, and technology in the classroom. Also of interest was the teachers’ dispositions on the use of technology in the classroom. At the time of the pre-survey, prior to student exposure to Dr. Herr’s teaching on technology in education, most of the students expressed at least a medium level of confidence with most classroom technologies. Among others, the technologies in question included; having students create online presentations, using websites for instruction, creating online surveys, and collecting student work electronically. However, in the area of directing student evaluation of large data sets, only one of the responders felt highly confident. The great majority of responders felt a moderate or low level of confidence with this activity.

The pre-survey results indicate that most of the responders came to Dr. Herr’s course with little fear of technology. This would stand to reason when considering the overall young age demographic of the teachers enrolled in the class. When questioned on the technologies they intend to use in the future, most were in favor of the use of online presentations, educational websites, photos for instructional purposes, and online posting of assignments.

**Free response data.** The free response data was of particular value in that it helped to establish the respondents’ previous experiences with TFA. About fifteen percent of the open-ended responses indicated the respondent never used formative
assessment in their classroom. Two thirds of those wrote “N/A” which likely indicated they were pre-service teachers and therefore hadn’t had the opportunity to apply any teaching techniques.

Most of those who had experience with TFA were enthusiastic about its effectiveness. As an example of representative response, one student wrote, “Formative assessment has been the premise of my teaching. It has given me the data I need to teach and re-teach my students. It helps to better understand where students stand in their knowledge of material.”

Further survey questioning tallied the number of responders who had experience with specific TFA techniques such as hand-raising, the one minute essay, exit card, class observation and frequent quizzes. The results supplemented and confirmed the distribution of TFA experience indicated in the open-ended response section.

Summary

Questions the pilot survey didn’t query concerned effectiveness of CFA. Such questions were reserved for the post survey. It was determined, for example, that student/teacher perceptions on the effectiveness of formative assessment techniques with regards to student engagement, motivation, metacognition, collaboration and accountability to learning were desired. Hence, such questions were added to the post survey.

IV. Interviews

Interviews with educators having varying levels of experience with CFA were performed in the summer of 2013. Of particular interest to this study were the recorded experiences from teachers who had practiced CFA techniques for at least a year. It was
believed that these teachers could render detailed, however verbal, illustrations of CFA in its authentic classroom usage. They were referred to in this study as Veteran CSP Teachers. Perceptions from teachers fairly new to CSP were also considered of value. Young teachers exposed to CFA in Dr. Herr’s classes and in professional development sessions would provide this study with the perspective of the freshly initiated. Finally, two individuals who – in addition to Dr. Herr – taught CFA techniques at the university level were queried on their experiences. All interviewees were generous with their time and eager to share their positive and negative experiences employing technology in the classroom.

**Interviews with veteran CSP teachers.** In the summer of 2013, eleven teachers experienced in the techniques of computer-based and traditional formative assessment were interviewed individually concerning their views on formative assessment and the various methods, both traditional and technology-assisted, they employed over the years. The interview sessions occurred over two weeks in July at California State University Northridge. The teachers were part of a summer professional development workshop given by the California Science Project. They were invited to the workshop as veterans due to their previous success with CFA. In the interest of acquiring perceptions of the effectiveness of CFA, these veterans were considered to be among the ideal subjects for interview. With respect for anonymity, the teacher names have been changed.

The questioning was directed towards various means of delivering formative assessment and the advantages and disadvantages of those methods. Traditional formative assessment (TFA) was understood as that which did not involve any computer technology in its execution. For example, the primary TFA method the interviewed
teachers used over the years was the art of questioning. Continuous Formative Assessment (CFA) was that which involved computer and web technologies. One widely used variety of CFA was the Classroom Response System, otherwise called CRSs.

Of interest in the interview process was the teachers’ perceived effectiveness of various methods of TFA, CFA, and specifics on how the teachers defined that effectiveness. The query process included questions on their teaching background, familiarity with practices of formative assessment, and their experiences with technology. The recorded interviews were then transcribed and coded for analysis. The complete list of questions is given in Appendix A. Many of these teachers also participated in the surveys.

**Formative Assessment.** The teachers expressed a necessity to formatively assess their students. In particular, Jackie, a middle school teacher of physical science, noted the immediacy of information gained through the formative assessment process, “Formative assessment is something you're seeing, what their understanding is, immediately so that you can grasp any misconceptions.”

Teachers mentioned that it can be difficult to get a good response rate by simply asking questions of the class. Many students are often shy to answer. Teachers may refine the art of questioning by calling on specific students in order to engage students who otherwise do not respond. Sampling the class in this way may give some indication of the full class awareness. For instance, if several randomly selected students respond to a question incorrectly or with no answer, the probability would be that most of the class has the same lack of understanding. If, on the other hand, the teacher isn’t as diligent in the questioning, the process provides a less than reliable metric for gaging student
understanding. Jackie expanded on the difficulties of obtaining full class involvement, “You would have three quarters on a good day actually participating and they would always be this low. (They) just sit back and not tell you anything and so it was difficult to measure what that quarter knew. I wasn’t having much success with that.”

The concept of recognizing student misconceptions came up several times throughout the interviews. Identification of student misconceptions has apparently been a long-standing challenge for teachers. They felt that the more immediately the misunderstandings could be identified, the more immediately they could be addressed. TFA methods, mentioned by interviewees, that revealed a more accurate and a more fully encompassing view of student understanding were; hand signals, sticky notes and lettered cards or spoons. These tools allowed for largely anonymous responses from students which helped to remove embarrassment if answers were incorrect. Using these techniques, responses from the entire class were found to be more common. Common TFA methods mentioned by the teachers were exit cards and frequent quizzing. These had a privacy element and gathered responses from the whole class.

When listening to the various TFA methods given by the interviewees, stories of how the methods were applied were often accompanied with the purpose for applying those methods. An example of the effectiveness of the anonymous response was given by Cathy. She told how she had her class use sticky notes:

I didn't realize just how powerful even sticky notes are. I tried it; I said, okay, here's two sticky notes, each. You have to write a question to me that you still don't get about this unit. What do you not get? I took all the stickies and put them up on the board. These were about atoms, this one was about isotopes. I saw, oh,
gee, isotopes had twenty. Okay, so now let's see, you guys are still struggling about isotopes, okay. I didn’t have them put their names on it on purpose.

Implicit in the above story is the expressly elevated participation and response rate among students over simple questioning of the class. With the student’s full involvement, this teacher was able to determine the knowledge level for a pressing question from a greater percentage of the class. She was able to gage this lack of understanding fairly quickly.

Janine was enthusiastic about assessing student learning through frequent quizzes. They gave her full participation from the class. When asked about the formative assessment methods she used, she said,

We use the standardized quizzes which were awesome because we could know right away whether what misconceptions were happening based on the question and answers... We cover the material and by the following Monday they were required to have taken the quizzes and we could look at and quickly say, "Most of the class got it," or, "Oh my God, most of the class missed that question. Let's go back and look at it." … And then take those questions apart and teach them how to answer the questions and then also to try to clear up any misunderstandings.

While Janine described the gathering of answers as “right away”, it should be noted that a weekend had passed before the collection of answers were received and students’ level of learning could be assessed. While the advantage was full class participation, this method did not allow for daily assessment. Another teacher described the problem:

A lot of times when you hand back work the students don't even read your comments back and so then a lot of misconceptions weren’t cleared out where
they weren’t addressed and they weren’t ever addressed immediately...Even if it was a weekly quizzes you wouldn’t hand it back until it's half through the next week and so you still had already gone half of the week and then you realize I needed to reteach that [concept] a week ago. Then by that point it's hard to get to back to re-teaching - get their mindset back.

Her story illustrated a significant break in the continuity of the teaching and learning process. Cathy also spoke of the delayed feedback problem associated with the grading of many quizzes. She found the more timely advantages of numbered or alphabetized spoons, “Someone had a real cool idea of spoons. On the table you have labeled spoons, A, B, C and D. If you have your questions, they could just hold up the spoon. No one else can really see it through the curve and what answer they're giving.”

Jeanette, teaching middle school biology, was yet another instructor who mentioned the unfortunate delay in formative feedback that was inherent in the grading of quizzes. She was enthusiastic about a CRS-type smartphone app that was recommended at the workshop by a fellow teacher. She noted a particular advantage, “I’ve asked for a CRS for years but they’re expensive and now this is a free [smartphone] app.” She relayed hopefulness in the new technology along with a frustration of roadblocks she had encountered in her desire to more efficiently gage the comprehension of her lessons. Some teachers have dealt with the lack of technology at their schools by intentional use of smartphones. Janine was able to have her class collect data on location using smartphones and a product called Vernier Probeware which electronically logged data in a photosynthesis experiment.
We were outside on the balcony and each group I'd make sure that there is at least one person in each group that had a cellphone or a computer. One could have a little portable netbook (computer), another student could have their iPhone, and yet another student might have a tablet (computer). So between them, the kids, they're entering their own data.

She explained that the students entered the data on a Google Docs spreadsheet which she uses in her course regularly for data collection and surveys. During the collaborative exercise, she noted that errors were quickly revealed, “You would see the trend of 6.5, 6.5 and all of the sudden 28 because somebody forgot to divide.” This was an example of a formative assessment performed in the context of peer comparison. The student group with the outlier data were able to note their likely error in the context of the predominate data entered by their peers. The electronic forms were used by several of the teachers in this way.

Over the two week period in which the veteran teachers were interviewed, I had the opportunity to observe some of their CSP workshop training activities. Pairings of the veteran teachers would give various science related lessons to an audience of less experienced teachers. In between the lesson activities, the entire group of teachers would gather for forum discussions. During these gatherings, it was observed that teachers, both veteran and new to the CSP, would share stories of new cloud technology applications they found particularly useful in their classrooms. Two of the more enthusiastically promoted apps were Edmodo, a social networking site designed for education purposes, and Socrative - a classroom response system with the ability to collect text input. Other technology and web tools used by the interviewed teachers in the application of CFA
included tablet computers, smartphones, various Google products, *Dropbox* for cloud storage of documents and *Virtual Labs* - a website where scientific experiments and data collection could be performed.

In deciding which classroom response smartphone applications were most useful in the classroom, Jackie explained, “It's like something that you wanted to have quick, fast, and easy. They come in, they test and they answer you're done in five minutes.” Ease of use was an issue. She also suggested that if the app that took more class time, it was less than conducive to instruction. She said that in a perfect world, she preferred that the students each have a laptop computer as opposed to a phone or tablet as there were fewer constraints in the use of laptops. She appreciated the universal formative assessment capabilities Google Form’s online forms and survey tools afforded and noted a particular advantage to its image insertion abilities, “You put in an image of DNA and it's labeled A, B, C, D, which are pointing to the paramecia or the period or something like that, because half of science test is the label or identify things on the…I couldn’t have done that on the quiz.” She also looked forward to a time when all student work was stored in the cloud as opposed to notebooks.

Cathy gave a story of how she worked within her school’s limited access to technology and expanded a lesson with social networking. She was enthusiastic about the real-time formative assessment that a social networking app provided in a distance learning format. Students gave a presentation on the planets from home via Edmodo that she was able to view in real time, “I gave them advice. I was able to check all the presentations as they were going.” She added that there was another advantage of collecting group data online in terms of grading and immediacy, “We can actually get all
the data together because I don’t want to collect 10 lab note books, figure out the data and then have us average it out. This is, they just input it into a form and we can get results immediately.” The math capabilities of the software would then allow for quick averaging of the data.

Mahya espoused about the collaborative assessment abilities of Edmodo, “If students are not sure if their hypothesis that they’re choosing is correct, they can talk to each other in Edmodo, or they can even ask their other teacher, “What do you think? This is what I think is going to happen. Am I on the same page? Can I test this hypothesis?” She was also in favor of the reduction of paperwork the technology delivered. Cathy noted the peer collaborative properties of social networking extended well beyond the classroom, “You get advice…do you show a graph this way and someone went, oh, try this, this, this and this. Then they link up all these other sites. I was doing technology and I found a ton of stuff. It's overwhelming, so I’m on overload.” The Edmodo social-networking was also appreciated by Connie, “One other thing I’ve used is Edmodo which is just like Facebook and the students’ love that they can do their homework from their phone. They get an alert when there’s a posting, so most of my kids really like that. Usually I have a link to a YouTube video; they watch it and have to answer some questions, so it’d be something simple.”

Ethical use issues regarding social networking were raised by the interviewees. Alicia’s school required permission slips be signed by parents of students using the technology. Cathy proceeded with the use of social networking carefully, “I don't turn on the ability for them to see each other's chat. I did with my honors classes near the end when I felt that they showed me that they were capable to be nice about it. The questions
they were asking were impressive. They did this at home, so I was impressed. Now I can, maybe, take it to the next level. It is something that I think as a teacher, you have to be comfortable with.” Her story advised the monitoring of student exchanges for civility as well as for the purpose of formative assessment.

The use of smartphones in Pablo’s class started more organically. After he’d asked the class to enter data on a computer, his students asked, “Can we just do it on our phone?” He allowed them to do so and noted again that electronic input aided in collection of student work and accountability, “Every group has to enter their data, and if they don’t, I’m going to know it.” He put this statement in contrast to earlier TFA methods, “If they’re just writing the data in their notebooks or on paper, I don’t know who’s writing what, or if someone’s writing the wrong information.” With these statements, he chronicled a transition in teaching and learning methodologies.

Alicia offered another example of combining technologies in CFA. She was excited about the capabilities of virtual labs and how they allowed her to do labs across several courses where prep for so many labs would have been impossible. She then had students input experiment results on a Quick Write spreadsheet. She also talked of the efficiency and ease with which the assessment was conducted.

Pablo added a note on the advantage of having a permanent digital record of students’ work concerning accountability to a student’s parents. “I know I can open my drive and everything that was done is there. A parent asks what their kid is doing in school, what the kid’s not doing … or if they ask what I’m doing. ‘What are you doing in your class?’ I can pull up one of the good kids, who I know did everything, and there
will be a list of all their documents.” He also noted an organizational benefit to digital records, “I have everything in one spot, instead of piles of papers all over my classroom.”

Elizabeth, who teaches middle school science, noted another advantage of the permanent record that involves both teachers, parents, and the requirement for evidence based learning:

Here's another thing, participation grade. It's always been a tough thing, and it's an argument between all the teachers so that we can be uniform about how we evaluate participation. It's actually called cooperation and work habits. The kids actually get a grade for it. The parents are always wondering, "Well, what does it mean? How do you get it?" It varies dramatically from teacher to teacher. Quick-writes are a perfect way to do a screen shot... so when the parent says, "Well, how come my kid got a U?" Here's the evidence. One of the things that had occurred to me is in an attempt to always have an evidence-based grade.

Evidence-based decision making is currently being promoted in California education from the top down (ACCJC, 2002). CFA techniques were reported by the interviewees as particularly useful towards fulfilling this requirement. They can record student participation and render documents that provide evidence of learning and accountability to parents, teachers and administrators.

The interviewees viewed cloud based CFA as an improved means of overall formative assessment. The ease with which CFA allowed for a permanent record on regular student progress to be gathered and maintained, the ability CFA methods achieved in real-time capture and sharing of student generated data, and the cost effectiveness that cloud technologies brought to formative assessment were all given
among advantages CFA had over traditional formative assessment methods. With reference to the learning parameters of engagement, motivation, accountability, metacognition and collaboration, the interviewees were also in favor of CFA techniques as follows.

**Accountability.** When asked about formative assessment and accountability, one teacher spoke of traditional collaborative projects she used that were designed to promote student accountability to both peers and to the teacher. She mentioned that peer pressure was a motivating factor as the group grade depended on evidence of teamwork. Her students also felt the need to be viewed positively by their teacher.

When asked what advantages she saw in collaborative exercises employing CFA, Connie mentioned accountability along with tracking ability. When the summarization of an essay was given as a group assignment, Connie sought to determine if her student’s really worked as a team,

I looked at the end and saw that only two girls had done anything and I gave them the credit. There was a boy that said, ‘no I did the whole thing’ and I went in the revision history and the girls hadn’t added a single thing. ...I went back to the very beginning and sure enough, he’d written the whole thing. Accountability is a big thing, being able to see everyone else’s work.

The tracking abilities of CFA were also mentioned by Lisa, who teaches physical science at a Los Angeles middle school, “I mean definitely when you sign in, everything you type is traceable back to you…you can't be distracted, you can't be doing something else, you need to paying attention because the whole class knows whether or not you were following or not.”
One interviewee gave representation to negatives in using CFA with respect to accountability. She mentioned that, in using forms to collect and post responses from the entire class, some students will rush to simply put in an answer without much contemplation. Their goal is just to complete the task and therefore the learning is less than productive. She did believe that the CFA methods were a step up in accountability over paper methods as student answer exposed to the class. However, that can also encourage the class clowns. She also recommended a participation grade be attached to the process as there will still be students who still don’t care to be involved.

Marilyn contrasted her previous attempts at engaging students using TFA with new techniques involving CFA:

They have to do something. I mean the very first time formative assessment was introduced to me; you tossed a question out into a class. Okay, six people might raise their hand. And even if you're a good teacher and you give wait time and you take multiple responses... But this way (using CFA techniques), they can all upload it. They can all see it. They can look down a line for common trends or ones that make sense or don't…It can be anonymous. The anonymity of responses helped promote student participation as students were less fearful of being identified and embarrassed with a wrong answer.

Several teachers noted how student accountability to the teacher and their own learning was increased tremendously through CFA methods. With a cloud-based spreadsheet projected in front of the class, students submit answers to teacher questions. Teachers would tell stories of students feeling obliged to contribute. Students without answers submitted were easily identified. Pablo, for instance, would call on the student,
“So-and-so, where’s your answer?” Admitting that he didn’t always get the best answers from some students during this process, he was at least achieving a high level of student involvement.

Another method achieving high levels of accountability were Google Docs used for entering data for lab reports. Pablo noted that this method allowed for easy collection of student work. Reflecting on previous difficulties in collection of student work, teachers told of how electronic submission of work and its traceability solved the problem of hard copy submissions that disappear. Lisa said, “When you sign in, everything you type is traceable back to you…Like in the quick write when you type in, when you don't type in everyone knows that you're not. Therefore you can't be distracted, you can't be doing something else, you need to paying attention because the whole class knows whether or not you were following or not.”

Teacher tractability and exposure of work to peers appeared to be the two most significant features of CFA contributing to student accountability. Because CFA required response from the whole class, it reduced instances where students could remain passive. CFA also allowed the teachers a better view of the percentage of class who were understanding or not understanding the lessons and the sort of misconceptions students had.

**Metacognition.** Dimension one of the NGSS standards prescribes that student learning be taken beyond the emphasis on content to the development of skills of scientific inquiry (NGSS 2, 2013). The goal is to further a student’s scientific metacognitive abilities bringing them to a point where they are self-motivated in habits of asking meaningful questions that are the foundation of scientific investigation (NGSS 2,
The interviewees were asked if they perceived better questions from their students as a result of CFA techniques. The initial responses were mixed. Alicia believed that she was absolutely observing higher-order thinking in her Quick Write responses. She noted that the Quick Writes drew deeper thinking from the students and were not reserved for questions regarding definitions. Pablo felt the questions he saw from students when using Google Docs may have been marginally better, “I guess because they have more information, they may have more difficult questions.” He said he still had to prompt students when unexpected data was displayed. However, he added, “That opens up further questioning, and more thinking questions; just two or three answers, but its conversation, instead of what just happened before because all their data would be in their notebooks.” Exposure to data was a recurrent theme in the interviews both in terms of the teachers ability to perform formative assessments and students peer review and self-assessment.

Jeanette talked about her process of encouraging questions from students and getting them to embrace, “student led learning and inquiry and stepping away from teacher led.” She said that it could be annoying to students as she refrains from answering their questions in favor of requiring them to investigate the problems and phenomena themselves.

Janine employed internet chat technologies in the teaching of her honors biology class. She monitored the questions students’ had for her on the chat line and was able to observe evidence of improvement in the students’ metacognitive processes. In using the technology she said, “I can follow their conversation and their thinking and actually used it for my Master's when we were doing inquiry because I could actually copy paste that
whole conversation as evidence as to how students were thinking.” While she didn’t note any particular increase in the development of students’ metacognition, the ability to monitor their thinking was a clearly apparent feature that did not exist with TFA. This story also provides an additional example of the permanent record feature of CFA techniques that can be used to confirm validation of evidence-based learning. Janine and Alicia suggested that collaborative properties of CFA improved student formation of metacognition. They argued that, in view of their peers, the students felt a necessity to organize their thoughts and employ categorical and higher order thinking skills.

Getting students to a metacognitive stage where they accept and integrate the process of investigative questioning as their own has traditionally been a challenge for teachers. CFA techniques were found by the experienced teachers to be a move in the right direction in this regard.

**Engagement and motivation.** Engaging and motivating students in STEM classes was an issue for some of the teachers. At least two teachers had difficulty engaging a class of students that were described as deficient in math skills. Another expressed that she had a challenge motivating her students even with honor’s students. Another teacher found that it was difficult to engage a class in a lesson on ecosystems. She stated the students couldn’t relate as they lived in a “concrete jungle”. For some classes, activities on such topics as Newton’s law provided the desired engagement. Another looked back at difficulties engaging students without current technologies.

And just trying to take kids outside and get them engaged and we did a lot of labs and stuff but there was no collection of data like scientific. The closest thing of technology was a calculator. That was it and the overhead projector which
consisted of the clear sheets that everybody lived and died by. You would use that to get your answers on and have kids come up and put their answers on their shared data that way... it was cumbersome definitely.

When the interviewees spoke of CFA benefits, collaboration was often mentioned in tandem with engagement:

Getting on the internet, it's more engaging...I think it's because of the features that the computers allow them to have. I think that it's engaging, because they can see their answer and compare themselves with each other.

Another interviewee noted improved engagement with CFA techniques:

The technology really helps students engage in sharing of data and looking up data, recording data. Recording on lab papers or just writing research or emailing each other. That kind of stuff, I've used a lot for them to communicate with each other and also with the whole class and also with me we use it.

Others applied technologies such as smart phones with photo and GPS capabilities to record STEM related field-trip observations.

One interviewee told a story about engaging a class by collecting information on stem-cell research and involved them in a discussion of their findings. She then employed CFA methods first by using a Google Form to collect and post students’ different views on the topic. Following that, she had her class use the Socrative smartphone app to submit their votes for each posted item. She felt this CFA technique had a real-time advantage:

If it was paper I would have to count everything and I would had to say, "Okay, for this measure the number was na, na, na" but this one I got see immediately
after voting and while voting was going on they got to see where is it standing, like is it going to pass, is it not going to pass.

She went on to say that she didn’t feel CFA was required to engage students. However, the CFA techniques used in this example helped to increase the level of engagement.

Another teacher noted that computer technologies were not perfect in terms of engagement:

I still have some non-par kids that just no matter what you do they just aren't really interested in participating. At home they have computer, they just don't want to get on it and do it. If it's not a game or something I guess. I don't know. I don't even know if they play games but I know that they're on the computer.

Another teacher echoed the sentiment by mentioning that while technology provided engagement opportunities, it had to be “purposeful”. If her students were using computers for busywork, they would not participate.

Clearly, the experienced teachers interviewed felt CFA techniques opened many new avenues with which to engage their students. They described new levels of involvement as result of students feeling obligation to contribute. The anonymity possible with CFA released their students from the embarrassment of being called on when they didn’t feel they have appropriate answers.

**Summary**

In the course of these interviews, it was found that levels of enthusiasm towards the use of CFA were high overall. The veteran teachers noted the high response rate featured in CFA techniques that greatly improved engagement and accountability, the collaborative advantages of CFA with its information sharing abilities, and CFA’s ability
to grant a window into students thinking processes and progress that made great strides towards witnessing and improving their metacognition. In addition, the exposure of students’ work to their peers was expressed by the veteran teachers interviewed as a motivational aspect of CFA.

**Focus Group Interviews with Project Grad Los Angeles (PGLA) Teachers**

During the same summer 2013 period the CSP Veteran teachers were interviewed, K-12 science teachers from the Los Angeles Unified school district participated in a professional development retreat hosted by the CSCS team. The teachers attended a two-week training session held in July. The teachers were taught with hands on approach in the methods of CFA. Over the duration of the retreat, the teachers would alternate in groups of 6 or 7 in planning science-class lessons for middle school students. While one group was designing lessons and activities, another group would be teaching their prepared lessons and associated activities to actual middle school students. Teaching activities involved a variety of collaborative data-acquisition and analysis activities associated with middle and high school science curriculum. The lessons were planned with guidance from CSCS team members. For many of these teachers, this was their first exposure to CFA.

The middle school students to be taught came from disadvantaged regions of Los Angeles and were recruited by a non-profit organization called Project Grad L.A. They were bused to the CSUN campus every weekday morning for a two-week period. The process was repeated with a second group of students the following two weeks. At the end of each two-week session, the teachers were interviewed in focus groups about their experiences with CFA. They were asked questions concerning their previous experiences
with formative assessment, their opinions on the effectiveness of CFA and any projected use of CFA in their regular classrooms following the summer training. The recorded interviews were then transcribed and coded for analysis. The complete list of questions is given in Appendix A. Many of these teachers also participated in the surveys.

The teachers ranged in age from early twenties to mid-fifties and taught from grades 6 to 12. Some had decades of teaching experience and others had as few as two years’ experience. The students they taught ranged from English language learners with little if any experience in the sciences to honors students. Courses taught by the interviewees included physics, biology, mathematics and natural sciences. Teacher names have been changed and places of employment are generalized in the interest of anonymity.

**Formative Assessment.** When thinking back to their own classroom experiences as students, few of the interviewees could recall being formatively assessed by their teachers. Referring to her AP Biology course, one teacher recalled, “All we had done is end of the chapter questions and vocabulary, and tests every two to three days, open book, so we wouldn’t complain. I got an “A” in that class, but I learned nothing; absolutely nothing.” This triggered another teacher’s observation, “Class discussion is not a traditional way of teaching. Everyone is supposed to be just listening to a teacher.” Her comment was in context of a middle-eastern cultural norm.

When asked what types of non-technology based formative assessment the teachers have practiced in their classes, most of the interviewees spoke of hand-raising. This was mentioned, by more than one of the interviewees, in the context of *warm-up questions* designed to gauge the students’ current levels of understanding. One
respondent made a division based on the type of information desired; depth of knowledge vs. what to teach. She noted the efficiency aspect of formative assessment saying that it was not possible in her calculus course to go over all the material given in the text. She also noted the importance of the feedback she received and that what one class needed to know varied from what another class needed.

Another interviewee noted how her school administration had been promoting the regular monitoring of student understanding. She described the details of the white board process she used to meet the directive:

Each student had a white board. We asked the question, gave them a couple seconds to answer it, put it on the white board, turned it over, and we say “flip.” They all flip the answer at the same time. At that point, you can kind of, as you’re scoping the room, you can see who’s got the right answer, who is maybe off. You can kind of do the percentage in your brain, and then you know what to touch upon to see maybe what you have to kind of re-teach.

This was a visual estimation means of data collection. Other methods mentioned by the interviewees were exit tickets, numbered sticks and pair-share.

One responder talked of a more conversational approach in formatively assessing her students, “With questioning, but it looks like a collaborative conversation with students.” Body language also, some teachers agreed, gave an indication of the students’ level of involvement, “If you're in the middle of practicing and they're day-dreaming or look stressed out.”

In the interest of accountability, a teacher described a Popsicle stick method as a way to enforce random selection of students during periods of questioning. Student
names are written on individual sticks and placed in a cup on the teacher’s desk. The teacher asks a question and then randomly selects a student-stick from the cup to call on. This kept the teacher from favoring or avoiding given students in the questioning process:

It’s a random choosing to see who was paying attention and who wasn’t, so if the student isn’t…there’s no opting out….We choose another student. The other student may know the answer…You then redirect the first student that didn’t know the answer, and they have to respond the same way that the second student answers so that they are now listening and they have accountability.

Another teacher said she did the same process using a smartphone app that would randomly pick students. It would keep statistics on students’ individual responses to inform the teacher of the students’ learning progress. Yet another teacher mentioned that an Edmodo poll could be used in place of the exit ticket. Descriptive statistics of correct answers and classroom progress was a noted feature of the polling program.

For many of the teachers, availability of technology in the form of computers in the classroom and Wi-Fi was limited or unreliable. One of the teachers was loaned laptop computers from CSUN’s CSCS team. With those computers, she was able to employ Quick Writes in her class. She noted that with repeated questioning, by projecting student answers on a screen in front of the class, students were able to visualize the development of their own learning. Anna, a teacher of middle school and high school science, told of the preparation required for a classroom response system:

What type of question you are asking, that's most important. For CRSs, last year I was trying to come up with some kind of high level questions. It's so hard. It's not like yes or no questions. For multiple choice, you don't want to just have basic
answers. There's no point in using CRSs. You want them to think, to discuss, to analyze something. To come up with a set of questions, it was hard also because mainly they are used in definition questions.

She continued noting the lengthy process involved when trying to come up with appropriate multiple choice questions and corresponding answers.

Many were exposed to CFA techniques in Dr. Herr’s classes but were not able to apply the methods in their schools of employment. However, during the workshops held at CSUN, they were given access to the technology, “I enjoyed these past two weeks because whatever we learned in Norm's (Dr. Herr’s) class, it was kind of hard to apply it with our school because we don't have the technology, but these past two weeks I've kind of experienced all of them.” This quote came from a teacher who looked forward to using many of the technologies to which she was introduced. She further stated that the practice sessions increased her level of confidence with classroom applications of the technology.

Google Docs spreadsheets were among the favorite technologies to which the teachers were exposed. Anna was particularly enthusiastic about a CRS smartphone app called Socrative. She lauded the app’s continuity aspect allowing for real time questioning without the need to pre-design multiple choice questions and corresponding answers.

The focus groups echoed the organizational aspects of technology in the classroom that were also recorded in the veteran interviews. In reference to Google Docs, one teacher said, “I think it will keep all their answers online in one place so that I can access from everywhere. I don’t have to worry about carrying papers to grade every day.”
The focus group teachers appeared quite knowledgeable about a wide variety of formative assessment techniques. They were cognizant of the values of regular assessment in informing their teaching and improving student learning. While most experienced technical support issues at their schools, they were excited about the potential of CFA techniques.

**Accountability.** Focus group teachers agreed that CFA appeared to increase student accountability. They referred to the requirements for students to sign in to a class spreadsheet and to answer the instructor prompts. One teacher noted, “They have ownership of all their input.” The ownership of responses a student was going to enter on the class spreadsheet implied accountability to themselves but there would also be accountability to the instructor. On the question of whether or not to include student names on a spreadsheet projected to the class, one teacher said,

> Unless they type in their name or something, you really didn’t know who did what, and kids could do whatever they wanted. As soon as they were forced to log in, so that you could keep track of who was doing what, I think it made the class a whole lot more accountable.

Again, this was accountability to the instructor seeking input from the whole class.

Most of the interviewees were new to the process of projecting a classroom spreadsheet consisting of student input. For them, it was a learning experience to see how a spreadsheet could help them graph and interpret data. Another teacher was always wondering if she was giving students enough time to answer questions during regular TFA class questioning practices. She noted that, because students type their answers into
the class projected spreadsheet, this gives the teacher a clear idea of the time it takes for students to process and react to a class prompt.

The improvement in student accountability that CFA techniques brought was perceived by the focus group interviewees to bring advantages beyond responsibility to learning. There were the logistic advantages of keeping role and having a permanent record of student progress. The projected spreadsheets also made for collaborative opportunities and developed metacognitive skills.

**Collaboration.** When questioned on collaborative aspects of formative assessment, the focus group interviewees gave stories similar to what the veterans mentioned; there was an advantage to the class seeing aggregate data as those groups with outlier data would recognize likely errors. One teacher provided an example of this form of whole-class collaboration in one of the regular courses he taught:

When you posed the question, I thought of my diabetes unit. There’s this one part where the kids are divided up into groups, about three or four kids, but then it comes to a point where we have to analyze a lot of data, and so there’s a group that analyzes the incidence of diabetes versus gender, and then another one does it with the relationship to race and whatever factors in, weight maybe.

Another teacher added that this form of whole-class collaboration put the students in a situation similar to that of practicing professional research scientists. An interviewee named Tony noted a time issue in the collaborative process, “My biggest problem was time. Especially with the data analysis, I kept getting questions, so I kept going into it further and further and further, and that ate up a lot of my time for other stuff.”
Some of the interviewees perceived an advantage to using technology in collaborative exercises. One teacher likened the whole class collaborative experience as an expansion on the pair-share technique with the added advantage of the visualization of data trends, “that wouldn’t have been possible without all the data from the class.” Referring to projected spreadsheets displaying student-collected data, a teacher said, “It’s so easy to compile the data and analyze it immediately.” She looked forward to applying the technique in her future course. Another teacher enthusiastically stated,

One of the great things here is, they’re doing the warm-up on a form, and then stuff on a spread sheet. The warm-up is supposed to be a simple question about what we did yesterday. You think … you’re hoping they got it, and immediately you’ve got feedback; there are about a quarter of the kids who still aren’t clear. OK, I’ve got to re-teach it right now. Or, “They got it.” That’s how it is a great tool.

This statement prompted another interviewee to mention that CFA promotes collective accountability, “It’s not like you’re turning in this secret paper to the teacher, the teacher is looking at and evaluating.” She noted the value of a community learning aspect that the CFA methods promoted, “It’s not even graded…but it is somewhat more valid to them, because it’s being seen by the public.” This was another telling statement championing the peer accountability aspects of CFA. In another instance she explained how a top student was found to have made a mistake and how this was revelatory to the rest of the class; mistakes could be made by even the best students. She then described herself as a forms addict who regularly used the Google Forms in formative assessment practices.
In general, the focus group believed that collaborative rewards were among CFA’s greatest features. The value in witnessing each other’s responses, the professional working atmosphere, the clear identification of trends, and the public exposure of responses that focused their achievement goals beyond that of making a grade, were all advantages that were not realized with traditional formative assessment techniques.

**Metacognition.** Internet information factored heavily in responses to questions concerning student metacognition. Describing her students as being self-directed to find answers, one teacher remarked on a class exercise combining a classroom spreadsheet with an internet search procedure:

> When I did my survey, there was a question about air resistance. (The internet) just provides an opportunity for them to find answers the way you do with technology. You don’t have to motivate the kids to learn. The technology is there…It pushes students to discovery …They’ll have more authentic questions, because of what comes through their mind, and we’re giving them the freedom.

While this was comment spoke of technologies and their use beyond the domain of CFA, it illustrated how a CFA technique such as the Quick Write spreadsheet promoted further classroom engagement and deeper questioning. She followed her comment with a comparison to earlier, less than ideal, instructional methods reliant largely on textbooks:

> This is such a wonderful extension capability, too. When you’re sitting with a science textbook in front of you, and maybe you’re the really smart kid, and you’ve read your material, you’ve done your workbook, you’ve got it … then what do you do? Extension by reading the next chapter? It’s different than saying, “OK, then I have some questions. Maybe you can research this and see
what you can find out, that connects with what we just did.” They can sort of orbit the material, if they’re that really great science student.

This was an example of an ideal situation supporting deeper learning. Another teacher noted that, when the teaching was textbook-focused, student learning was chapter by chapter and the motivation for further review was virtually non-existent. The emphasis in such cases was on the chapter test. With such a statement, she suggested that self-motivated deeper investigation was more the property of CFA techniques.

In summary, CFA techniques freed the students to explore their learning beyond a linear format and gave them easier and immediate access to real-life examples. This freedom motivated an extension of learning from a test into a more self-directed learning for discovery.

**Engagement and motivation.** On the subject of classroom engagement and motivation, a single sentence summed up the situation many teachers faced, “I have to spend the first two days teaching them how to yawn silently.” Several of the teachers said they were up against a culture of technology:

They’ve all out-technologied me by a long shot… They come in, and their expectation is *OK, what are you going to do to entertain me, or I’m going to go to sleep*…They’re so colorful at home, and all wired up; they come to your classroom, and for me, I didn’t have all these tools. I didn’t know any of this technology. Boring; it’s a chalkboard, and it’s on the board, and worksheets. Worksheets are not colorful. They have to share, or I minimize it to a point where they have to use a magnifying glass to read it.
This teacher further explained that she was referring to a class of sixth grade cadets. She elaborated that even the disadvantaged students had cell phones. Another interviewee had a contrary experience, “Where I work, the students don't have technology. A lot of them don't have cell phones; they don't have computers and internet at home. It's very low income. Even just setting up a Gmail account, they get really focused and get really into it.” In each account, the teachers felt that we are at a time when technology is necessary in engaging and motivating their students.

Making a comparison with traditional methods a respondent said, “When they tell you, give them a worksheet, map and plot it on the map … it just loses a lot of that “wow” factor. They’re living in a technology-driven world.” She explained that when her students did the same project using the internet, it was much easier for them to investigate further. With a traditional work-book method, they would need to go to a library for further exploration. This teacher was exposed to CFA originally during weekend professional development sessions held during the previous two semesters.

The interviewees were largely enthusiastic about CFA in its ability to engage their classes and as a motivator towards learning and assessment. It appeared that when CFA techniques were used, there was no longer a need to “teach students to yawn silently”.

**Technology issues.** Though enthusiastic about the technology, many of the teachers were faced with technological roadblocks at their schools of employment. Even if computers were available, there were issues of access and tech support that made their use less than feasible, “It’s just really hard, the technology in our school. There are only two labs, a laptop cart. You have to schedule that at least a month in advance, and even then, you’re just crossing your fingers that you can get it.” Others had learned not to rely
on the available technology, “You don’t have any kind of support in terms of equipment or personnel for trouble-shooting issues.” This was a frustration shared by many of the interviewees. In reference to an initiative that would eventually issue iPads to all LAUSD students, a teacher noted:

They don't have the infrastructure to run them…There is no way you're going to be able to run an entire school worth of iPads at the same time on the systems that most of these schools have. Our server basically crashes if you get more than just the teachers putting their attendance in.

Another teacher mentioned that she had a set of CRSs but she had to share them with another department. Much of the technology available in the schools, according to one of the interviewees, went unused because the teachers at her school didn’t have training in its use. Language platforms were an issue in an Armenian school, “The smart boards don't have the Armenian font for them to design any lessons, so they use it as a chalkboard.”

Some had considered the use of educational smartphone apps but found that their school was opposed to the idea. The district’s concern was if the smartphone was broken while being used in class, students’ parents would hold the school accountable. This motivated another interviewee to offer, “At our school, they’re not supposed to have any electronic devices out in class. Everybody’s going to have to shift, in terms of policy.” She was echoing the notion that we are in an age where technology in education is a norm.

While there were frustrations with the tech situation as it prevailed, some felt that training would be helpful, “Because of my lack of computer knowledge, I need to keep
practicing and practicing in order to grow, and to reinforce it.” This teacher lamented that she only received a half hour of professional development on technology every two years.

**Summary**

The teachers described the windows into their student thought processes that various CFA techniques made possible. These reports were accompanied by illustrations of improvement in classroom engagement, motivation, accountability, metacognition and collaboration. The fact that these teachers were dealing with digital natives gave them a sense of obligation to seek CFA techniques in order to engage and motivate their classes. They were in agreement that CFA methods requiring student input increased a students’ level of accountability. The teachers noted a non-linear advantage CFA brought to the questioning process that improved metacognitive skills, in contrast to traditional chapter by chapter learning approaches. The more authentic collaboration possible with CFA techniques was also extolled by the focus group interviewees.

**Interviews with two CSCS Team Members**

Along with the case study of Dr. Herr, it was considered pertinent to the discussion of technologies used in formative assessment to garner the stories of other CSCS team members. What was their history with the CSCS group? What did they feel were the advantages of CFA in the classroom? What was their perception of the effectiveness of formative assessment techniques on student engagement, motivation and accountability? To answer these and other questions, interviews were conducted with Dr. Virginia Oberholzer Vandergon and Dr. Dorothy Nguyen-Graff.

Dr. Vandergon, like Dr. Herr, had been with the CSCS group since its inception. Dr. Dorothy Nguyen Graff had only a few years of experience with the CSCS group.
Most of these interviews focused on classes that each professor taught to non-majors in their departments. These were the courses where each professor found the most use for CFA techniques.

**Interview with Dr. Virginia Oberholzer Vandergon**

Dr. Vandergon worked doing professional development for CSP starting in 2000. Echoing a statement made by Dr. Herr, she said there were a number of science teachers that weren’t as versed in their subject as they could be. This was the purpose for the CSP summer workshops. She held that the CSP had been using technology for many years. The newer focus on CFA started only three years ago when various online tools specifically appropriate for educational use became available.

**Engagement.** Dr. Vandergon has been teaching a biology class to pre-service K-12 teachers, many of whom she describes as having a fear of science. Her goal has been to get them to a point where they feel confident they can teach science. She also teaches a genetics course to science majors. She feels the Quick Write is a good tool to get these student groups involved in the day’s lesson,

“It's not something I grade. It's just something to get them going,” she said in response to my question on how she gets the students engaged, “It's a quicker way to assess them. I have sixty students. And I'm doing it every day right now, so there's no way.”

**Formative Assessment.** With respect to formative assessment techniques, Dr. Vandergon used several techniques but primarily the Quick Writes spreadsheet. She noted that the electronic version was new but she had been doing the activity for years in the form of the *one-minute survey*. Students would answer her prompts on index cards. She would run this activity three or four times throughout a two-hour class session.
Similarly, she did a traditional version of a CRS, “I did CRSs before CRSs...I used to use index cards. Colored index cards and I still do this when I'm in a situation where I don't have (electronic) CRSs. So they have laminated four number cards and they hold up their numbers and so every student had, and I've used them again since I arrived on campus.” When asked if she felt there were any advantages to electronic formative assessment, she said, “I think the benefit with technology is that I can actually go back and see whether there are trends in my students’ responses...I have a record.” This was an answer heard in other interviews as well. “I think it can help them look at how other people are formulating their answer” she said in response to a question on the advantage of projecting student answers to the whole class. “I don't think technology makes or breaks a class...if you're a bad teacher, even if you're using technology, it's not going to help your students. I think technology is just a new tool too, and it helps me think about what I'm doing in the class.” She also championed the ability of technology to capture student ideas but cautioned that it can be overwhelming, “You also have to be prepared in case it goes down...But once you learn how to use it, it's much quicker.”

**Collaboration.** A collaborative tool Dr. Vandergon used was called the Frayer Model (University of Minnesota, 2014). It consists of a word given in the center of a page. Around the word, the paper is partitioned quarters assigned to; the definition of the word, characteristics of the word, examples of the word and non-examples of the word. Her students work in groups filling out the model (Figure 6). The professor then projected the students’ responses on the screen in front of the room for whole class review.
When asked about potential advantages to the CFA full class collaborative process she noted the larger set of examples and ideas to compare and highlight. She also mentioned the permanent record aspect:

I think my students like using the Cloud, especially for the collaborative aspects of it. As I said, the 102 class I teach, the non-majors class, there's a lot of group work so they can work on the group documents. It's all there. It's all captured. I'm shared on it. I can look at their progress. So I like that aspect of it.

**Metacognition.** When asked if she felt the technology helped students ask better questions, Dr. Vandergon said, “I think what I find is that, they're making better connections to what they're doing in lab versus what they're learning in their textbooks… I think it can help them look at how other people are formulating their answer.”
Accountability. On the effectiveness of CFA towards a student’s accountability to their own learning, Dr. Vandergon felt the collection of activities was of the greatest benefit, “What makes them more accountable is actually coming to class. And they feel like coming to class is worth it because I have things that they do in class.” However, she didn’t perceive any particular boost in student grades as a result of her use of CFA techniques:

I think if the students take advantage of how they're doing on the formative assessments, they can be beneficial. I'm not convinced that my students are doing any better or any worse than they have in the past…I do think that a few students, it's helping them that are on the low end. But your ‘A’ student's going to be your ‘A’ student. It doesn't matter what you're doing.

Her impression that CFA techniques were most effective with struggling students was encouraging to this study with its focus on the problem of students struggling in STEM courses and majors.

Interview with Dr. Dorothy Nguyen-Graff

Dr. Dorothy Nguyen-Graff teaches as a lecturer in CSUN’s Department of Chemistry and Biochemistry. She has been with the CSCS team for seven years. She was active with the group assisting in training at their CSP professional development summer sessions. Her interest in CFA techniques appeared to be purely organic in that she was not required, in her position as a lecturer, to do research or write grants. When the CSCS team started promoting technology in formative assessment, she felt a lack of experience:

I do the professional development in the summer and I felt kind of stupid because I’m just kind of following along and I do not really understand it but I pick key
things up here and there. Until you really have to use it is when you really understand all the little nuances and all the little details that, the frustration that teachers have. I’m teaching them but I’m not really doing anything. I feel really jealous in a way.

The disconnect she described compelled her to attempt the CFA techniques she was teaching in her own classrooms. She brought the techniques to a class of 70 non-science majors in an intro to chemistry course. Consistent with her highly energetic nature, she described the experience:

I did tons and tons of Quick Writes in the beginning because I was kind of trying to get students interested in it. Some students really liked it. Some students complain about the technology. I go, what the hell’s wrong with you? I overcame that technology, right? I was like if that didn’t work, we thought of something really quickly and something really different. We didn’t dwell on it.

In order to contribute to the Quick Writes, she had students sign on with the various devices they brought to class. These included laptop computers, tablet computers and smartphones. Some laptops were borrowed from Dr. Vandergon.

**Formative Assessment.** The questions Dr. Nguyen-Graff posted to the Quick Write were often procedural and an attempt to find out what the students knew or didn’t know. Her prompts were done in the stream of her lecturing and were not preplanned. Of the possible advantages of the Quick Write, she said, “I can see what they’re thinking…in terms of; do they understand? It’s like the fact that I make them take something down, they are paying attention more.” The last statement helped to answer my questions on her methods of engaging students in her class.
Engagement and motivation. When asked what she does to engage students who don’t have a deep interest in the sciences, Dr. Nguyen-Graff told of a variety of exercises that related to the various majors represented in her class. She gave such examples as the units she has done covering environmental sustainability with respect to climate change, textile products, food and materials used in interior design.

In recollection of her previous teaching of intro to chemistry class, Dr. Nguyen-Graff noted she didn’t have previous experience teaching the class without technology. As she put it, “I took on this course because I could use the technology.” She felt the students would lose interest quickly if she was restricted to a traditional lecture format. She mentioned that, even in her chemistry class taught to science majors, her teaching had to change. As a lecturer, the science majors she teaches are freshmen, she explained. Hence, while they were majors in the subject, they were also new to university education. Many were not familiar with the work it took to be a student. Keeping that population of students motivated was often as challenging as it was with the non-majors.

Dr. Nguyen-Graff mentioned that students stayed with her class to the extent that, by the end of the semester, she estimated ninety percent who started the course were still attending. This persistence rate was excellent by comparison to other sections, “My colleagues who’ve taught this in the past, (said) by the end of the semester about fifty to sixty percent of the students still come to class.” Whether her much improved class persistence rate was due to her use of technology, her teaching style or a combination of the two was not clear.

Collaboration. Dr. Nguyen-Graff told of a activity she adapted from an air-pollution data-mining exercise she learned from Dr. Herr. She had students collect data
concerning daily carbon dioxide emissions. Student groups were assigned to search the web for disjoint portions of the data and to post their results on a Quick Write spreadsheet. This had an advantage over having student groups post their data on the board as the Quick Write spreadsheet has graph creation capabilities. One graph is created from the data collected by the entire class. This allowed Dr. Nguyen-Graff and the students to view any patterns in the data and also to identify outlier data.

**Accountability.** Dr. Nguyen-Graff attributed student accountability to their own learning in her course to group work activities, whether they were monitored with CFA or TFA methods. With regards to the effect of technology, she added, “They help each other out in the group. I'm kind of overseeing all of their work online as I scroll down through their presentation.” The presentation she referred to was done through Google Docs which had a presentation application similar to PowerPoint.

Dr. Nguyen-Graff still uses a good deal of TFA techniques in the form of daily homework and group work. She says that CFA techniques can be cumbersome as there is student training involved. The task of getting students signed on takes class time. In many cases, she says it was just more efficient to send student groups to the board. She intends to adjust her future usage of CFA techniques in order to achieve their advantages without sacrificing class time to needed to cover the required course content.

**Summary**

Hearing the stories of the veteran professor / experienced CSCS member in juxtaposition with that of a lecturer relatively new to CSCS and with moderate teaching experience was enlightening. In each of the value categories, their stories had similarities to each other and to the responses from Dr. Herr’s students. The differences with respect
to student responses were in how direct their explanations were in connecting the value
categories to CFA techniques. For example, many of the student responses stated with
certainty that CFA techniques made students more accountable to their own learning.
This was also supported in the student survey data. Dr. Vandergon and Dr. Nguyen Graff
were less definite and talked about group work and other TFA activities in their
assessment that also made their students accountable. The professor and lecturer had
reasonable access to technology. Similarly to the student interviewees, they still had
technical issues. Theirs were in terms of available time and training of students in the use
of the technology. Notwithstanding, the challenges did not deter them from the use and
promotion of technology in the classroom. They still found noteworthy value in its
application with regard to formative assessment, collaborative activities, student
accountability, class engagement and student motivation. Dr. Vandergon’s assertion that
CFA was more effective with struggling students was noteworthy as the impetus of this
study was on the retention of students who struggle in STEM programs.

V. Action Research

For the last eleven years, I have been a math instructor at Woodbury University,
a small southwestern non-profit private 4-year university. In the interest of a more
complete understanding of CFA techniques, I tested applications of CFA techniques in
my own classes. At my university, the only widely available technology was projectors
and screens and internet access. I decided to use a cloud based technology that
employed the use of smartphones. Over the last decade, I have viewed cell phones and
smartphones as a threat to classroom management. Students were often distracted from
relevant course discussions by engaging in phone media activities. It had been a
challenge to engage students while competing with the messaging activities in which some are much more eager to participate. The problem could be diminished using a strictly enforced and re-enforced classroom anti-phone mandate and/or by regularly calling on the offenders with class discussion questions. However, it was my experience that complete elimination of the problem was rare, even with the most stringent of classroom policies.

Conceding to the lure of the smartphone on a student’s attentiveness, I took refuge in the realization that there is significant computational power in these devices. Indeed, many educators have appreciated their potential for classroom learning (Gikas & Grant, 2013; Rismark, Solberg, Stromme, & Hokstad, 2007; Keegan, 2005; Livingston, 2004). Coders have met this realization with excellent learning applications such as Socrative and Edmodo. Scanner applications are in a class of smartphone programs not likely developed with learning primarily in mind. In combination with cloud storage such as Dropbox or online photo applications such as Picasa web, scanned work could present the instructor with a window into student thought developments. As I projected the student responses in matrix form on a screen in front of the class, students could also see their work in the context of their peers’ work. I would then note specific examples among the student work in guiding the learning.

The scan and post method of CFA produced results not unlike those in the aforementioned Ink Survey or Near Pod (for the iPad) as they allowed me to ask questions that required students to submit graphs and other renderings. They were not limited to text input. However, the scan and post method had some distinct advantages over Ink Survey and Near Pod: Economically, as students were using their own
smartphones, there was no need to purchase additional machinery. In addition, the *scan and post* process was not platform specific or proprietary. Because the CFA applications employed in my classes were available universally for smartphones of varying brands, there was no need to achieve buy-in from administrators and/or fellow educators on a certain product or software.

**Methodology of the Action Research.** Over two semesters of a trigonometry course for non-majors, the Camscanner app was employed in formative assessment of student learning. Students were asked to load two programs to their smartphones; Camscanner and Dropbox. In each of the two semesters, there was only one student in each class that did not own a smartphone. In each of these cases, a neighboring student was willing to *scan and post* the student’s work.

Data gathered from the class consisted of my observations of student responses to prompts using the *scan and post* technique of formative assessment. The observations were recorded in daily journals. Three objectives of my observations were outlined in the journals as what was:

- Presumed about student understanding of given concepts
- Learned about student understanding of given concepts
- Adjusted in teaching of concepts following applications of CFA

**Observations.** I have found that teaching trigonometry to non-majors requires close monitoring of the students’ levels of understanding. Many students struggle with concepts such as applications in basic trigonometric functions, identities, vector operations and the aforementioned section on descriptive geometry. To lessen their difficulties with these concepts, it is important they are given a strong foundation on properties of
triangles. To motivate this, I asked the students what they already knew about triangles. Rather than selecting various students for contributions, the whole class was required to enter their answers on a smartphone CRS app called Socrative. Answers such as; ‘three sides’, ‘angles total 180 degree’, and ‘equilateral’ were projected on the screen in front of class and led to an engaging class discussion.

In another application of Socrative, the students were asked to enter the definition of similar triangles. I was concerned that the problem was too easy but was surprised to find, of 18 students responding, only one had an answer that was close to correct. Students entered apparently random guesses such as ‘same lengths’, ‘isosceles’, and ‘acute, scalene, obtuse’. It was a valuable lesson in that I was so sure that most of the class knew how to deal with similar triangles. The ability to quickly survey all the students in the class made it clear that similar triangles was a topic that needed to be reviewed.

The teaching of common sine and cosine values was initially approached by having the students draw 60 degree reference angles in a unit circle. The angles were then to be labeled with the appropriate ordered pairs. Once this was done, the students scanned their drawings to a Dropbox folder. These were thought to be, in my mind, rudimentary exercises. It was believed that enough examples had been presented. Only a few students might be expected to present a flawed drawing. There was some consideration that the labeling of ordered pairs might be an issue. The actual results were quite the contrary. It was nice to see the scans revealed the students labeled the ordered pairs correctly. However, several students’ renderings of a 60 degree angle more closely resembled a 45 degree angle (Figure 7). This was something that was not expected and was an important
insight into student misconceptions. Interpretation of reasonably approximated angles in the trigonometry course was critical in a number of applications. The lesson was then adjusted to accentuate the importance of reasonably accurate representations of angle measures.

In the same class, when students were found to have difficulty with an application problem describing an architectural example, it was useful to have them draw what they thought the problem was describing (Figure 8). The problem described a television antenna mounted to the top of the empire state building. It gave two angles of elevation from a point on the ground some distance from a point directly below the antenna. One angle of elevation was given to the bottom of the antenna and the other to the top of the antenna. Sensing the students were having trouble interpreting the word problem, they were asked to draw their own depiction of what they were reading. Two of the several depictions posted were correct. Most of the others had a similar common error. The challenge was then to find a way to get them all to interpret the word problem correctly. There was a profound advantage in displaying the collection of student perceptions and then discussing the posted results with the class. Not only did the activity engage the whole of the class, but it provided the students additional perspectives from their peers on how to understand the application.

The next exercise asked the students to use their understanding of the sinusoidal-wave graph and translations to render a graphical representation of a trigonometric function. Most students did well at translating a cosine curve exercise but most students had difficulty labeling the horizontal axis (Figure 9). The lesson was then adjusted to
emphasize methods of labeling graphs. The result was much-improved marking of the axes in the follow-up exercise (Figure 10).

![Figure 7. Student renderings of 60 degree reference angles in a unit circle](image)

![Figure 8. Student Renderings Describing an Architectural Site](image)

![Figure 9. Student Renderings Showing Translations of a Cosine Curve](image)

![Figure 10. Student Renderings of a Cosine Curve Correcting for Horizontal Axis Labels](image)

**Collaboration.** In addition, *scan and post* and the Socrative CRS allowed the involvement of the whole class in the review of their work. As student responses to my prompts were gathered and projected to a screen at the front of the class, students were naturally engaged as their own posts were reviewed in the context of the posts of their classmates. As noted in existing literature, there appeared to be a learning advantage to the collaborative evaluation process between students (Orsmond, Merry & Reiling, 2002;
Topping, 1998). However, it did become apparent over the semesters that there was a limit to the number of times a given CFA technique could be applied in a given class period before students became fatigued or disinterested. Varying the activities, both traditional and technology assisted, was helpful in keeping the students engaged.

**Summary**

The CFA techniques employed in the trigonometry class had been particularly effective in revealing and addressing the breadth of misconceptions students hold with respect to a variety of mathematical concepts. Traditional formative assessment methods, such as the art of questioning, the exit survey, and the evaluation of class-work and homework also revealed such misunderstandings. However, the traditional methods lacked the immediacy in the revelation of student learning errors. The impact on my depth of understanding of student misconceptions as observed from the full matrix of responses could not be overstated. My assumptions of student cognition had been proven wrong so consistently through the use of CFA.

It was my observation, as many of the interviewees mentioned, that student accountability, engagement and motivation were greatly increased through the use of CFA. The immediacy and depth of information provided by the *scan and post* technique, in particular, was invaluable in directing and redirecting the teaching. For administrative interests, I see the potential use of the permanent record achieved in these CFA techniques in program review and assessment studies. As a result of this practice in CFA and its usefulness, I look forward to continued application of CFA methods in future classes.
VI. Final Survey of Teachers Exposed to CFA Techniques

The intent of the final survey was to achieve a sense of the perceived effectiveness of CFA techniques from a sizeable audience of STEM teachers who have been exposed to CFA methods at various levels and in an assortment of courses and professional development sessions. The survey was submitted to two-hundred potential responders at the end of the spring semester of 2013. The nearly three-quarters response rate was considered robust and provided useful data on the research question and sub-questions.

The survey was partitioned into three main sections:

- Experiences of the subjects CSUN students
- Questions for Teachers Who Have Not Used CFA in the Classroom
- Questions for Teachers Who Have Used CFA in the Classroom

The latter two categories separated subjects who had no experience in the use of CFA with their own students from those who did have the opportunity to employ CFA in their own classes. The responses from those with no classroom experience would give data on the level of acceptance of CFA techniques in theory. The responses from the experienced group would give data on usefulness of CFA techniques based on their experience.

Responders’ experiences as CSUN students. This section was answered by all who took the survey. It asked the teachers to recall their experiences as students in CSUN courses taught with traditional formative assessment methods and courses taught with CFA techniques. The questioning in this section started with logistics. It asked for the specific courses in educational technologies the teachers attended at CSUN and the various tools they employed in those courses. Forty-five percent of the responders were
exposed to CFA in CSUN’s credential program. Thirty-two percent were exposed to CFA in one of two masters programs: Science Education or Educational Technology. The remaining twenty-three percent were exposed to CFA in either of two summer professional development programs held at CSUN: Project Grad L.A. and the California Science Project.

As students, the responders were clearly exposed to a wide variety of CFA tools (Figure 11). These included the *Quick Write* free response spreadsheet, various Google products including *Google Docs, Google Sites* and *Google Moderator*, cloud storage facilities such as *Drop Box* and *Picasa web*, and several smartphone apps such as the *Camscanner* that allows the smartphone to scan images, *Edmodo* – a social networking application designed for collaborative educational activities and *Socrative* – a classroom response system (CRS).

![Figure 11. Teacher Reported Exposure Levels to CFA Techniques as Students](image)

Following the logistics section of the survey was a series of questions concerning perceived educational benefits of formative assessment in its two variations: TFA and
CFA. Table 3 presents results of the survey items that questioned the teachers on their perceived effectiveness of CFA upon their own learning as students in the CSUN education program. The data is given in descending order with the item receiving greatest percentage of votes in favor of CFA on top. Following the table, the reading of the response data is further discussed in terms of metacognition, collaboration, accountability, engagement and motivation.

Table 3

Responders’ perceived effectiveness of CFA: Reporting as CSUN students. 141 survey-takers responded

<table>
<thead>
<tr>
<th>Survey Item</th>
<th>TFA %</th>
<th>No Difference %</th>
<th>CFA %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning from peers</td>
<td>1</td>
<td>2</td>
<td>97</td>
</tr>
<tr>
<td>Self-monitoring as a learner</td>
<td>0</td>
<td>4</td>
<td>96</td>
</tr>
<tr>
<td>Awareness of alternative problem-solving strategies</td>
<td>0</td>
<td>7</td>
<td>93</td>
</tr>
<tr>
<td>Accountability to peers during instruction</td>
<td>1</td>
<td>5</td>
<td>94</td>
</tr>
<tr>
<td>Awareness of various ways to interpret data</td>
<td>0</td>
<td>8</td>
<td>92</td>
</tr>
<tr>
<td>Awareness of alternative perspectives</td>
<td>1</td>
<td>7</td>
<td>92</td>
</tr>
<tr>
<td>Accountability to instructor during instruction</td>
<td>4</td>
<td>5</td>
<td>91</td>
</tr>
<tr>
<td>Engagement during instruction</td>
<td>3</td>
<td>10</td>
<td>87</td>
</tr>
<tr>
<td>Awareness of my own thought processes</td>
<td>2</td>
<td>11</td>
<td>87</td>
</tr>
<tr>
<td>Accountability for my own learning</td>
<td>0</td>
<td>18</td>
<td>82</td>
</tr>
<tr>
<td>Likelihood of my ideas being recognized by the instructor</td>
<td>3</td>
<td>14</td>
<td>83</td>
</tr>
<tr>
<td>Asking questions in class</td>
<td>6</td>
<td>26</td>
<td>68</td>
</tr>
</tbody>
</table>

Throughout the table it is shown that the teachers - in the role of students in education classes - overwhelmingly perceived CFA techniques to be an improvement in the various constructs of accountability, collaboration, metacognition, engagement and motivation.
**Collaboration.** At least ninety percent of the responders believed CFA excelled with respect to the survey items concerning its effects on collaboration. These items included: *learning from peers, awareness of alternative problem-solving strategies, awareness of various ways to interpret data, and awareness of alternative perspectives.* The highest percentage of respondents, ninety-seven percent of the 141 teachers, believed they learned more from peers in CFA taught courses than in courses taught with traditional methods of formative assessment.

**Engagement and motivation.** The survey items dealing with engagement and motivation scored lower in the perceptions of the teachers. These items included: *engagement during instruction, likelihood of my ideas being recognized by the instructor, and asking questions in class.* Only sixty-eight percent of the teachers taking the survey felt that CFA was more effective in getting them to ask questions in class. Twenty-six percent perceived no difference between CFA and TFA in this regard. While a large percent of the responders felt that they were more likely to ask questions in a class taught with CFA, just over a quarter of the responders felt just as likely to ask questions in a class using TFA techniques. Six percent indicated they were less or much less likely to ask questions in the CFA class.

**Accountability.** Student accountability to the instructor was perceived to be higher in CFA courses than in non-CFA courses by ninety-one percent of the responders. Eighty-three percent of teachers felt more accountability for their own learning in the CFA courses than in non-CFA courses. However, the result here includes a good number of responders, eighteen percent, finding no difference in learning accountability as a function of the two course delivery methods. None of the responses registered a feeling
of less accountability in individual learning. The greater balance of responses, better than ninety percent, indicated that CFA made them feel more accountable to their peers.

**Metacognition.** More than eighty-five percent of the teachers believed classes they took that were instructed with CFA made them more conscious of their own thought processes and problem solving strategies. Well more than a third saying it was much more effective. Eighty-seven percent perceived a greater tendency to ask themselves further exploratory questions regarding STEM course content when they were taught with CFA techniques.

**Teachers Who Have Not Used CFA in the Classroom**

The next section of the survey was completed by individuals who have been exposed to CFA techniques in Dr. Herr’s classes and CSCS team-taught professional development workshops but have not yet had the opportunity to apply them in teaching practices. This was because they were pre-service teachers or because they do not have the technology available at their institutions. Fifty-five of the 141 survey-takers answered this section.

The initial series of questions regarded potential use of CFA in their future classrooms. Just over half indicated they would apply at least one CFA technique in the classroom sixteen or more days a month, given the availability of the technology. Nearly ninety percent indicated they would use CFA a technique at least once a week. Two of the forty-six responders indicated they would not use CFA techniques at all. The next few survey items focus on features of CFA and TFA that are the most appealing to the teachers.
The Quick Write registered as the most popular of the CFA techniques among the teachers who hadn’t yet applied CFA in teaching. Fifty-two percent of the responders said they would use the technique sixteen or more days a month. Ninety-six percent indicated they would use it at least once or twice a month. Only two of the forty-six responders indicated no interest in using the Quick Write in their class at all. It is worth noting here that the Quick Write is the method Dr. Herr used most often in his classes. Hence, it was the CFA method with which the responders had the most common experience.

Potential use of the Scan and Post technique received the least votes in terms of potential usage with sixteen-percent expecting not to use it at all. However, sixty-three percent of responders expected they would use it at least once a week. Another twenty-one percent would use it, though less frequently.

The other CFA techniques given mention on the survey displayed an average of fifty-six percent of responders indicating expected usage of at least once a week. Twenty-six percent, on average, would use the techniques less frequently. An average of ten percent of responders saw no expected usage of the remaining techniques.

When asked whether they believed students would be more engaged in a classroom that used CFA verses classrooms that used traditional methods of formative assessment, responders overwhelmingly felt CFA classrooms were more engaging (Figure 12). Only one of the forty-five responders predicted no difference in the two methods of assessment. None believed that TFA was more engaging.
One responder believed that TFA would provide a better view of students’ understanding of a given topic (Figure 13). Eighty-nine percent of responders believed CFA was more effective in that regard. Nine percent believed no difference would be found between the two formative assessment methods in a teacher’s awareness of student understanding.

Figure 12. Responder’s Predicted Level of Student Engagement

On the benefit of providing a window into students’ misconceptions, again, eighty-nine percent of the responders believed CFA techniques would excel over TFA methods (Figure 14). Four percent answered in the contrary and seven percent believed neither method provided an advantage of the other in exposing student misconceptions.

Figure 13. Responders’ Predicted Level of Awareness of Student Understanding
The teachers ranked CFA highly in its ability to motivate learning in each of the Next Generation Science Standards (Figure 15). The least ranking was given to CFA in its predicted effectiveness in the promotion of student questions. However, CFA was still thought to be better than TFA on this item by seventy-five percent of the responders. Nine percent thought TFA would do better and sixteen percent predicted no difference. The most notable vote cast for CFA was on the standard of \textit{obtaining, evaluating and communicating information}. In that category, ninety-six percent of the teachers felt that CFA would be the most effective. Fifty-five percent marked that it would be much more effective. Five percent believed TFA was better in this instance.
Figure 15. Teachers Predicted Rankings of The Next Generation Science Standards in Classes Taught With CFA vs. Classes Taught with TFA. The vertical axis represents number of respondents

Engagement and motivation. Another series of questions investigated pre-service teacher perceptions of the effect of CFA and TFA on student motivation along three parameters; recognizing value of a task, fostering self-efficacy, and willingness to complete tasks (Figure 16). When asked by which method they felt students would better recognize the value of a task, seventy-five percent of the teachers registered their choice for CFA, though only fourteen percent felt it would be much more effective. Eighteen percent predicted no difference in this regard. Seven percent believed traditional methods would work best in getting students to see the value of a task. Pre-Service Teachers’ Predicted Rankings of Motivation Characteristics
Figure 16. Teachers Predicted Rankings of Motivation Characteristics in Classes Taught with CFA vs. Classes Taught with TFA. The vertical axis represents number of respondents.

Seventy-seven percent predicted CFA would work best in fostering self-efficacy with twenty-seven percent believing it would be much more effective. Seven percent supposed TFA would be more effective. Sixteen percent hypothesized no difference.

CFA’s predicted effect on motivating students to complete tasks was given a ninety-one percent vote of confidence by the teacher-students. Thirty-one percent felt it would be much more effective. Only one of the forty-five responders believed TFA would be more effective in encouraging a student to complete a task. Seven percent predicted no difference.

**Formative Assessment.** On the survey, predicted adjustments to instruction were partitioned into five sub-categories (Figure 17). Sixty-six percent of responders predicted they would be more likely to provide additional examples in a course where they
employed CFA techniques than in one using TFA. Seven percent felt they would give more examples in a class where they used TFA techniques. Twenty-seven percent believed that either technique had no advantage over the other in this regard.

Eighty-one percent felt that a class taught with CFA would more incline them to adjust the pace of their instruction. Twenty-eight percent believed it was much more likely to encourage them to adjust their instructional pace. Nine percent believed that the TFA methods would more encourage them to adjust the pace of instruction. Another nine percent hypothesized no difference between the two methods towards influence on pace of instruction.

Adjusting the sequence of instruction was found be a more likely result in a CFA-taught class by seventy-three percent of the teachers. A quarter of them felt they would be much more likely to adjust the sequence of instruction in the taught with CFA. Seven percent hypothesized that changing instructional sequence was more likely if they taught using TFA. Sixteen percent believed that influence to change the sequence of instruction was not a function of the assessment technique used.

Asked if they expected they would be more likely to provide alternate ways of explaining in a course taught with CFA, eighty-four percent of responders believed they would. Only one responder of the forty-five believed that they would be more inclined to offer alternate explanations using TFA. Fourteen percent believed that CFA and TFA were equal in predicted likelihood of motivating alternate explanations.

Eighty percent of the teachers hypothesized they would be more likely to repeat concepts taught in courses employing CFA. Forty-percent believed they would be much more likely to do so in the CFA courses. Ten percent believed they would be more likely
to repeat concepts in courses taught with TFA. No difference was registered by twelve percent of responders.

**Predicted Tendency to Make Adjustments**

![Bar chart showing predicted tendency to make adjustments in classes taught with CFA vs. TFA.](chart.png)

*Figure 17.* Respondents Predicted Tendency to make Adjustments in Classes Taught with CFA vs. Classes Taught with TFA. The vertical axis represents number of respondents.

**Teachers Who Have Used CFA in the Classroom**

Sixty-one percent of the responders, 86 of the 141, had the opportunity to use CFA in the classroom. The greatest share of those practicing CFA were in-service teachers who were enrolled in the master’s program at CSUN. In that program, they took the 600-level technology in education courses taught by Dr. Herr. They taught K-12 courses in physics, biology, chemistry, natural sciences and math.

The experienced teachers were asked to indicate the CFA tools with which they practiced (Figure 18). Most of the eighty-six teachers who responded in this section selected *Quick Write* (62%), Collaborative Data Tables (78%), Collaborative
Presentations (65%) and Surveys (83%) as the techniques they used. Least used CFA tools among the experienced teachers was *Submit and Vote* (28%) and Collaborative Drawing/Mapping (31%). CFA techniques with moderate use by the teachers were the Classroom Response Systems (43%), Collaborative Text (52%), Scan and Post (43%). In each case, just over a fifth of the responders indicated they had not used at least one of these given techniques. However, that left nearly eighty-percent in each category noting that they had used each method with a frequency of once every two weeks or more. The overall results of question 33 indicated a high implementation rate of CFA among the CFA-experienced teachers.

*Figure 18. Experienced Teacher Reported Usage Levels of CFA Techniques*

The distribution of CFA tools used by experienced teachers shown in *Figure 18* is not unlike the distribution of CFA tools to which all responders were exposed as students (see Figure 11).
Engagement and motivation. When asked whether they believed students were more engaged in the classes they taught with CFA verses classrooms they taught with TFA, ninety-three percent of responders felt CFA classrooms were more engaging (Figure 19). Two of the eighty-six responders believed that TFA was more engaging. No difference in the two methods of assessment was perceived by five percent of the responders.

**Awareness of student level of engagement**

![Graph depicting awareness of student level of engagement]

*Figure 19. Experienced Teachers’ Reported Awareness of Student Level of Engagement*

Eighty-three percent of the CFA-experienced teachers felt CFA was more effective than TFA in inspiring students to see the value of a task. Thirty-one percent felt it would be much more effective. Twelve percent perceived no difference and five percent believed traditional methods worked best in this respect. Eighty-two percent felt CFA worked best in promoting self-efficacy in students. Twenty-eight percent believed it to be much more effective. Five percent believed TFA was more effective and fourteen percent saw no difference.

CFA’s perceived effect on motivating students to complete tasks was thought by eighty-two percent CFA-experienced responders to work better than TFA. Thirty-nine percent felt it was much more effective (Figure 20). Three of the eighty-two responders
believed TFA was more effective in inspiring students to complete tasks. Fifteen percent perceived no difference.

**Experienced Teachers’ Rankings of Motivation Characteristics**

*Figure 20.* Experienced Teachers’ Rankings of Motivation Characteristics in Classes Taught with CFA vs. Classes Taught with TFA. The vertical axis represents number of respondents.

**Formative Assessment.** Concerning awareness of the students’ level of understanding, ninety-five percent of responders perceived CFA was more effective. One responder felt that TFA provided a better view of students’ level of understanding (Figure 21). Four percent believed no difference occurred between the two formative assessment methods in a teacher’s awareness of student understanding.
Ninety-three percent of teachers who had experience teaching with both methods, believed that CFA provided a better window into students’ misconceptions (Figure 22). Seven percent felt TFA was more effective in this regard. None of the responders believed either method provided an advantage of the other in exposing student misconceptions.

CFA-experienced teachers were asked if they were likely to make the following adjustments to instruction; providing additional examples, adjusting the pace of instruction, adjusting the sequence of instruction, providing alternate explanations, and
repeating a concept to insure understanding (Figure 23). In two of these categories, *providing additional examples* and *providing alternate ways of explaining*, none of the responders perceived TFA to be more effective. Ninety-two percent of responders believed they were more likely to provide additional examples in courses where they employed CFA techniques than in those where they used TFA. The results were similar with the item regarding *alternate methods of explaining*.

Eighty-six percent of responders felt when they taught with CFA they were more inclined to adjust the pace of instruction. Thirty-five percent believed they were much more apt to adjust their instructional pace when teaching with CFA. Eleven percent realized no difference between the two methods. Two percent believed that the TFA methods were more likely to prompt them to adjust the pace of instruction.

Adjusting the sequence of instruction was found be a more likely result in a CFA-taught class by eighty-three percent of the teachers. Thirty-four percent of the CFA-experienced responders felt much more likely to adjust the sequence of instruction when teaching with CFA. One of the teachers felt that changing instructional sequence was more likely when they taught using TFA. Sixteen percent believed that using either CFA or TFA did not influence their decisions to change the sequence of instruction.

Eighty-three percent of the teachers believed they were more likely to repeat concepts taught in courses employing CFA. Nearly forty-percent believed they would be much more likely to do so in the CFA courses. Four percent believed they were more likely to repeat concepts in courses they taught with TFA. Thirteen percent responded that the neither of the two assessment techniques were more likely than the other to cause them to repeat concepts.
Tendency to Make Adjustments

Figure 23. Experienced Teachers’ Tendency to Make Adjustments in Classes Taught with CFA vs. Classes Taught with TFA. The vertical axis represents number of respondents.

**Metacognition.** Ninety-seven percent of the responders believed CFA was more effective in helping students analyze and interpret data (Figure 24). This was the most notable result in favor of CFA with sixty-two percent believing CFA was much more effective. One responder believed that TFA was better in this instance and one opined no difference.

Another science standard where CFA was perceived overwhelmingly to be the better method of valuation was *Obtaining, Evaluating and Communicating* information. TFA received no votes on this line item. Seven percent of the CFA-experienced teachers perceived no difference. The remaining ninety-three percent believing CFA methods were most effective in allowing students to obtain, evaluate and communicate information.
The experienced teachers who have used CFA ranked it highly in each of the NGSS Dimension I categories. They gave their least ranking to CFA’s effect in promoting student mathematical and computational thinking. Nonetheless, CFA was still thought to be better than TFA on this item by seventy-five percent of the responders. Five percent thought TFA did better in this regard. Twenty percent perceived no difference.

![Chart showing experienced teachers' rankings of Next Generation Science Standards in classes taught with CFA vs. TFA.](image)

**Figure 24.** Experienced Teachers Rankings of the Next Generation Science Standards in Classes Taught with CFA vs. Classes Taught with TFA. The vertical axis represents number of respondents

**Summary**

With the relatively large response rate, the final survey was considered a success as the primary exploratory device for this study. The perceived efficacy of CFA techniques in the minds of this audience who have been exposed to them and those that have put them into service was apparent. Their responses for the most part suggested the use of CFA techniques could potentially deliver profound improvements to student learning in areas of engagement, motivation, accountability, collaboration, and
metacognition. A discussion of the meaning and value of these observations follows in chapter five.
Chapter 5: Interpretations & Conclusions

In this chapter, an examination of the chapter 4 data is put into context with respect to the research question and its significance in the discussion of the importance of formative assessment given in the literature review. This process begins with a synopsis of the study comprising of a review of the elements and the logic with which they were assembled. This is followed by a discussion including; a comprehensive analysis of the collected data, an evaluation of the data with respect to the current academic dialogue, an illumination of themes that developed in the course of the data collection and review, and concluding discussion of the data and its effect in endeavoring answers to the research questions. Finally, recommendations for teachers and researchers are suggested.

This research initially concentrated on two problems related to student success with regards to STEM education. The first issue focused on the gatekeeping properties of math and science courses in the general education curriculum of non-majors. The second matter concerned the low retention rate of students who chose STEM majors. Along the path of possible solutions to these issues, root concerns common to both matters were identified. Motivation and self-efficacy in the classroom have been found to improve retention (Onwuegbuzie, 2000; Street, 2010). Formative assessment in the STEM classroom was recognized as a stimulus to motivation (Hewitt & Seymour, 1997). This rendered a transitive connection between formative assessment and retention of STEM students. With a renewed focus, best practices of formative assessment were explored. Continuous Formative Assessment was identified as an under-researched and promising avenue to explore in the identification of solutions to the research problem. This led to two primary research questions:
(1) What are the perceived influences of continuous formative assessment using collaborative cloud-based technologies (CFA) on student engagement, motivation, collaboration, metacognition, and accountability in STEM classrooms?

(2) What are the implications of CFA for reaching the learning goals expressed in Dimension 1 of the Next Generation Science Standards (NGSS)?

The purpose of this qualitative research was to investigate the perceptions of new and experienced teachers with respect to the value of Continuous Formative Assessment (CFA) in addressing the issues of gatekeeping and low retention of students taking STEM courses. Formative assessment in regular applications can expose student misunderstandings as they occur. This allows an instructor to adjust the teaching in an effort to impede a student’s ascension into lack of comprehension (West, 1991). In that spirit, this research considered the most consistent, efficient and effective formative assessment techniques towards the promotion of student retention and success in STEM courses. Along the way, it was found that CFA techniques gave rise to new and innovative pedagogy.

The research investigated CFA techniques have upon the quality of teaching and learning in STEM classes. The subjects in this research were teachers at various levels of experience with CFA. Some had taught with CFA techniques for as much as ten years. To triangulate the findings, several techniques were used to approach the study. These methods included classroom observations, ethnographic and phenomenologic interviews, surveys, and my action research. The teacher interviews were performed both individually and in focus groups. The survey data consisted of queries unique to this study as well as previously collected survey findings. The audio interviews were
The ex-post facto methodological design served this study well. Where a longitudinal approach could have offered a stronger statistically-based argument for cause and effect of given formative assessment techniques, the qualitative approach used here brought the study a personal dimension. Numerical data was still of particular value in gathering collective opinions. However, the interviews and action research delivered representation of subjective insights numbers couldn’t provide. The period in which this study was conducted allowed for the capture of opinions from teachers who were given to traditional methods of teaching. The same subjects had then been exposed to the cloud-technology based methods of CFA. This was an ideal situation.

Summary of Major Findings

The chief results of this study were in the perceptions of teachers exposed to CFA who believed that CFA held great promise for improved formative assessment in learning categories of student engagement and motivation, collaboration, metacognition, and accountability. In addition, CFA was not just the application of technology in the classroom but incorporated and promoted completely groundbreaking pedagogics. CFA techniques were overwhelmingly favored over TFA by survey takers and interviewees in each of the learning categories.

Formative Assessment. The vast majority of teachers believed that formative assessment was very beneficial to informed and effective teaching and student success in the STEM classroom. Most agreed that CFA techniques offered advantages over traditional methods. They noted the much improved timeliness of the window into
student cognition leading to swiftness in responsive feedback. Teachers valued the permanent record of student contributions that is a feature of CFA and the reduction of papers to be collected. Where TFA techniques such as the use of posted sticky notes and exit cards are useful in assembling responses from the whole class, they lack the feature of a permanent record.

The shift in teaching pedagogy that is often experienced by teachers who implement CFA is reflected in Pedro’s story where he told of the increased student accountability and more deliberate exposure to students’ ideas that he was afforded through computer and smartphone communication. His view of student work was more restricted when his students were writing in notebooks. Some disadvantages of CFA were also noted by teachers. This was primarily evident in the focus-group interviews and were largely related to school and district limitations. In the individual interviews, simplicity of practice and time used in the implementation of CFA techniques was important. This aligned with the theory of Technology Acceptance Models as ease of use and usefulness of the tools are key issues in the acceptance of a given technology (Davis, 1985; Mathieson, 1991, Venkatesh & Davis, 2000).

In my observations of CFA techniques as used by the various teachers and in my own application of the techniques, I found that - as with TFA methods - there could be great advantages to using CFA correctly and significant opportunities missed if the methods were used incorrectly. For example, in any method of questioning a class - CFA or TFA, if the teacher is not actively engaging all students in the questioning process and scaffolding questions based upon their responses, then a primary advantage of the formative assessment activity is lost.
It was clear that the CFA Quick Write technique had the ability to grant the teacher visibility of answers from each student in the class more effectively than a traditional show of hands. However, what the teacher did with that information was important. In the observation of Dr. Herr’s class, an excellent example of the scaffolding process was made evident. In a CFA Quick Write exercise, he asked the teachers in the class for their definitions of formative assessment. The answers were displayed to the class. He then followed the question by asking if, based on the answers displayed in the Quick Write, they would move on to the next topic. This put the class in the mindset of teachers. They had to think about the answers they saw and what level of class learning the collection of answers indicated. The teachers were then expected to render their decision in a subsequent column of the Quick Write. Dr. Herr’s teaching moment used the art of questioning at its best and also displayed a great feature in the CFA method of showing peer responses to the class.

It was clear to me that the subjects observed, surveyed and interviewed were eager to employ cloud technologies in formative assessment. They believed in the improvements that CFA methods promoted in engagement, motivation, metacognition, collaboration and accountability and were enthusiastic about realizing these advantages in their own classrooms.

**Engagement and motivation.** An engaged student has been found to be a motivated student (Gasiewski 2011; Gellin.2003; Pike 1999; Pike and Killian 2001; Rocca 2010). In the words of Gasiewski (2011), “There is a long and well established link between academic engagement, performance, and persistence, which is particularly relevant to STEM undergraduate education” (p. 5). The perceived value of CFA
techniques in their abilities to engage students in the STEM classroom were given a high ranking by the interviewees and the greater percentage of responders in the final survey. Those who hadn’t had the opportunity to employ the techniques in classrooms of their own clearly looked forward to doing so with varying degrees of regularity. This was an important result that offered remedy to interview comments noting that students were well versed in technology being “wired up” at home and were bored in the classroom. In the free response section of the final survey, one teacher wrote, “They are always on their phones or tablets anyway; it would be nice to deter their attention over to what we’re doing in class.” Most of those who had used the techniques in their classrooms continued to use them regularly though different techniques were favored by different teachers.

Final survey data indicated that CFA was perceived to excel in advancing students’ self-efficacy and ability to see the value of a task. This gave support to CFAs importance in aiding characteristics of motivation found in Eccles and Wigfield’s (2000) expectancy-value theory. When the focus-group interviewees mentioned real-life applications that were inherent to a biology class, it was suspected that students would see the importance of the assignment. In such cases, intrinsic motivation was realized as it hinged on whether or not a student understood the value of the task (Ryan & Deci, 2000). However, when one teacher noted resistance from students as a product of an emphasis on a math-involved process, motivation appeared to shift to an extrinsic state. It was not clear whether CFA techniques would stimulate what authors Ryan & Deci (2000) eluded to as a more positive form of extrinsic motivation that fostered an “attitude of willingness that reflects an inner acceptance of the value or utility of the task” (Ryan & Deci, 2000, p.55). However, it was a promising result that ninety-one percent of survey
respondents who were experienced with CFA techniques perceived it to be most effective in the general motivation of students.

**Accountability.** Apparent intents of CFA techniques observed, such as the Quick Write, Scan and Post and Socrative, were to achieve full class participation and documentation of learning. The relationship between individual student accountability and effective student learning has been established in a number of articles (Burton, Krechevsky & Rivard, 2010; Carroll, Hautau, & Williams, 2005; Slavin, 1987). Authors Davis, Mero and Goodman (2007) state that, “Accountability implies that one is being monitored and will subsequently be required to justify one’s performance or decisions to others” (p. 4). It has been found to impel people to render more thoughtful decisions (Ford & Weldon, 1981).

Documentation as a learning-motivated practice of observing, recording, interpreting and sharing through various media has been reported to support accountability to one’s self as well as accountability to peers. Documentation can provide a window into student understanding that is most often not as visible in a summative test (Burton, Krechevsky, & Rivard, 2010). Peer influence was also noted present in observed collaborative projects conducted with both TFA and CFA methods. As mentioned in chapter 4 by teacher interviewees, the classroom setting provided incentive for students to be accountable to collective as well as individual success. A blend of group rewards and maintained personal accountability are necessary for optimal student learning (Slavin, 1987; Carroll, Hautau, & Williams, 2005).

The observed teacher’s personal desire to succeed as students was evident with some of the more vocal teachers observed. CFA techniques seemed to be particularly
effective as the teachers desired to accommodate Dr. Herr’s request for their input. This was apparent in teacher interviews and my observations of the Quick Write process performed in Dr. Herr’s classes. All teachers were required to provide an answer on the Quick Write that would be observed by both the Dr. Herr and the class. Postings were not submitted anonymously. The teachers’ names were given on a spreadsheet that was projected to the class. With their names displayed, an impetus in accountability was realized. As an observer participating in this exercise - my name among the others - I felt compelled to put my best answers forward. I recall a number of instances where I would revise an initial response posting to get it just right. I had a desire that my answers would stand out from my classmate’s posts. I witnessed other teacher responses being revised in the same fashion. It was apparent that filling out the Quick Write spreadsheet had a competitive element for at least some of the teachers. The Quick Write exercise was clearly an in-the-moment engaging process with strong elements of collaboration and accountability.

Accountability has been defined in terms of answerability to an external audience (Schlenker, Britt, Pennington, Murphy, & Doherty, 1994, p. 634). In this study, the external audience included both the teacher of a student’s class and a student’s peers. In addition, accountability in this study includes answerability to one’s self. Accountability has also been researched in two classifications; outcome based and procedurally based. The former related the final result of student performance to a given standard. The latter referred to a qualitative appraisal of a student’s procedure used to achieve an outcome but with an absence of focus or evaluation of the outcome (Davis, Mero, & Goodman, 2007; Beach & Mitchell, 1978).
In some cases, Quick Write questions were process oriented. The teachers were not expected to know solutions but to offer claims backed up by their reasoning and thought development. Collaboration was often incorporated where teachers discussed before they offered an answer. As an example; in Dr. Herr’s class, teachers were paired up to discuss how they could create an atmosphere where public mistakes become positive learning experiences. A Quick Write was set up to receive their responses. This led to a whole-class discussion where the various team responses were deliberated. At other times, accountability was outcome oriented. This was the case, for example, when Dr. Herr was polling the class to determine if teachers knew what conditions were required for water to reach its boiling point.

Enforced accountability does not always ensure better learning. When the focus of and exercise is strictly on the outcome, less than desirable effects can result. These could include students feeling pressured and avoiding important procedures to achieve the desired outcome (Davis, Goodman & Mero, 2007). Authors Davis, Goodman & Mero (2007) recommend process accountability, where assessment of student learning emphasizes their adherence and understanding of procedure. The authors state, “process accountability reduces the pressure to explain and instead becomes a process whereby the individual describes the actions taken.” CFA techniques support either process or outcome oriented assessments.

There is also an ethical consideration attached to student accountability. The emancipatory nature of education requires that students of all racial and gender backgrounds should have their voices heard with equitable consideration (Freire, 1971; Gardner, Gardner, Dean & McKaig, 1989; Tisdell, 1993). Authors Saundra Gardner,
Cynthia Dean, and Deo McKaig (1989) called for objectives and undercurrents that “encourage nonhierarchical, mutually supportive, and empowering modes of thought and behavior” (Gardner, Dean & McKaig, 1989, p. 64). In the STEM classroom, the power of the anonymous collection of all student responses realized through CFA techniques would seem ideal in support of this goal. The display of ideas is the primary feature of the Quick Write, for example. Identification of the source of contribution, while still of significance, is secondary.

**Metacognition.** The perceived effectiveness of CFA and TFA in stimulating the evaluative form of metacognition was addressed in the survey item querying *awareness of my own thought processes.* An overwhelming number of respondents believed CFA to excel in encouraging a student to assess their own learning. One consideration for this response is that, with CFA techniques, each student’s thoughts are exposed to the entire class much more so than they are with TFA. Self-awareness would naturally set in that would motivate a student to review their thinking in the context of answers submitted by the rest of the class (Zimmerman, 1989; Bandura, 1986).

The importance of responses specifying the power of CFA in recognizing student ideas in class cannot be overstated. Placing value in student questions and contributions motivates better class participation (Gasiewski 2011; West and Pearson 1994). Learning is virtually absent until the student is involved in a questioning process (Thalheimer, 2003). A probe on the apparent usefulness of CFA and TFA towards students’ internalizing of problem solving questions was addressed in the survey item querying *self-monitoring as a learner.* This question was distinguished from the question on awareness of thought processes with the specification that *self-monitoring* was a student’s
ability to recognize their own errors. The similarly overwhelming response indicating
CFA techniques were most effective in this area could again be attributed to the exposure
of student’s work to the class at large.

A quarter of the surveyed teachers believed they were just as likely to ask
questions in a class taught with CFA as they were in a class taught with TFA. Indeed,
TFA techniques can be quite effective at drawing questions from a class of students that
are otherwise hesitant to speak up. Among the more popular TFA techniques mentioned
in the focus-group interviews was Exit Cards which are designed specifically for the
purpose of drawing questions from students.

**Collaboration.** Significant advantages of peer feedback in the process of
formative assessment have been observed in the literature as a suitable aid in the
promotion of student learning (Orsmond, Merry, & Reiling, 2002; Cooper, 2000; Dochy,
1999; Topping, 1998). The gains of peer assessment have been valued on par with, if not
superior to, that of instructor assessment (Topping, 1998). Decisions rendered in the
outcomes of peer assessment have been reported to be more objective when paralleled
with self-assessments (Orsmond, Merry, & Reiling, 2002).

CFA techniques were particularly well suited to collaborative processes and
provided many opportunities for peer review. Technology brought the ability to project
student data and written responses to the whole class and made peer assessment a regular
feature of the observed classrooms. In such exercises, all participants had the opportunity
to appraise the work of their peers and to evaluate their own work in that context. The
teacher assisted the process noting misunderstandings as well as correct and ideal posts.
In the process of facilitating, the teacher had the opportunity to identify exemplars among
the students. The use of exemplars has been shown to improve student understanding of subject standards enabling students to render more impartial conclusions than would be possible in purely self-assessing methods (Orsmond, Merry, & Reiling, 2002). They are particularly powerful when they are presented in contrast to one another where elements of a high quality exemplar can be juxtaposed with elements of a low quality one (d’Alessio, M. A. & Loraine L. L., 2013).

Collaborative technologies have aided what has been described as knowledge construction (Beldarrain, 2006). The teachers interviewed noted in several instances the value of aggregating the data of the entire class and making that data available for all students to view. They mentioned the ability for student groups to quickly see if their data fit the pattern developed by their peers. Identification of outliers was readily possible if such data didn’t fit the patterns. This sort of collaborative process was much easier performed using CFA methods according to the teachers surveyed. The process of knowledge construction was particularly evident in the wiki exercises performed in Dr. Herr’s classroom. Wikis are a sort of collective blog though are more permanent and education-focused in nature (Godwin-Jones, 2003). When Dr. Herr instructed his class of teachers to assemble knowledge contributions into a collective web-page, his class was learning through the process of teaching. Such techniques have been used to promote student interaction and motivate student’s autonomy over their own learning (Beldarran, 2006; Augar, Raitman, & Zhou, 2004).

Beyond collaborative data collection and peer critique, technologies found in CFA methods had also allowed for wider opportunities of peer-to-peer and student-to-teacher online discussion. The educational social networking app, Edmodo, peer to peer
internet protocol services such as Skype, advanced web-conferencing services and email have bridged distance restrictions (Beldarrain, 2006). Teachers interviewed in this study encouraged this type of shared communication and considered it part of their teaching pedagogy. Cathy’s story, given in chapter 4, richly illustrated how collaboration in the CFA environment has expanded on several fronts including synchronous exchange of ideas over distances, real-time teacher delivered formative assessments, quick feedback capabilities, efficient organization and the logging of permanent record of learning.

Students concerns with peer assessment found in the literature noted that it sometimes lacked specificity and, in such instances, was not well suited to self-improvement (Lin, Liu, & Yuan, 2001). This observation was also made by Dr. Norm Herr in his classes. His guided peer review in an exercise regarding the creation of websites included a whole class assessment of peer reviews. The teachers’ written critiques of their classmates’ website content were evaluated by the class for levels of specificity and applicability in order to improve the value of the assessment.

The realizations of significantly better collaborative abilities that were reportedly evident in CFA techniques represented a radical shift in pedagogy. These technology-enabled peer learning methods were what Collis & Moonen (2005) described as contribution-oriented. They promoted metacognition by involving students in “doing things and thinking about things they are doing” (Bonwell & Eison, 1991, p.2). It represented a paradigm shift that casted the role of the instructor as less a facilitator and more towards the position of partner in learning (Beldarrain, 2006; Collis & Moonen, 2005). CFA techniques predisposed students to the more professional aspects of science
where collaboration is the norm, not the exception (Kraut, Egido, & Galegher, 1988; Bozeman & Corley, 2004; Camarinha-Matos & Afsarmanesh, 2005).

In this section, it is worthwhile revisiting a chapter 4 quote noting the value of transparency in collaborative learning. An interviewed teacher said of class-posted student contributions, “It’s not even graded…but it is somewhat more valid to them, because it’s being seen by the public.” In this revelatory statement, we see how collaborative and engaging activity in the CFA classroom supports procedurally based accountability (Davis, Mero, & Goodman, 2007; Beach & Mitchell, 1978).

**Contributions to the Field of STEM Education**

Supporting evidence on the perceived effectiveness of CFA towards the promotion of dimension 1 NGSS standards was found in each of the data collection methods. The most direct indications of this were found in the final survey data. In each of the eight Dimension 1 categories, CFA was believed to be more effective than TFA by no less than seventy percent of the teachers experienced in the use of CFA. In standards (4) analyzing and interpreting data, and (8) obtaining, evaluating and communicating information, it was favored by better than ninety percent of the survey takers. A general scan of the free response data collected in the survey displays many instances where teachers note the advantage of CFA in several of the Dimension 1 categories.

This paper brings a discussion of the influence of cloud-based formative assessment on pedagogy to the existing education literature. During this time where a plethora of educationally related technologies are introduced seemingly daily, there exists not so much a question of technology use but how technology changes modes of delivery in order to improve education. It is imperative that the importance of pedagogy precedes
that of the use of technology such that we assure and advance excellence in teaching and learning (Parkay, Stanford, & Gougeon, 2010; Ascough, 2002; Watson, 2001). With this valuation of pedagogy and the student-focused STEM classroom in mind, voices of those who are exposed to pedagogically-motivated use of technology and their experiences and dispositions in that use are here given representation.

Some teachers are not looking back. This was evidenced in the interview with Dr. Dorothy Nguyen-Graff where she noted that she only agreed to teach, “because I could use the technology” and that students would not be as well engaged in her class if she were without ability to incorporate CFA techniques. Similarly, Dr. Norm Herr alleged that he felt his teaching approaches were at a severe disadvantage in instances where he did not have CFA technologies.

Limitations

The availability of subjects exposed to CFA techniques was limited to a self-selected group of teachers at a singular location. The character of their exposure to CFA was not at all unbiased and was delivered very much in the vein of championing and promotion of the techniques. We need to consider whether the subjects, particularly in the survey responses, were telling me only what they thought I wanted to hear. Indeed, many of the survey-takers came to the program with a certain amount of “buy-in” either as experienced professionals looking for professional development or new teachers looking to favorably complete requirements of certification. While, as students, they were being introduced and taught CFA techniques, they were teachers in the role of students and hence already had a good degree of what it meant to be a student. The pre-survey results indicate that most of the responders came to their CSUN courses in which CFA
methods were introduced with little fear of technology. This would stand to reason when considering the overall young age demographic of the teachers enrolled in the classes.

This was not a scientific study with the intent to support or fail to support a given hypothesis. There were no rating comparisons on the survey. The primary limitation in my study is that it is limited to self-report of teacher perceptions about CFA. Hence, these endorsements cannot be taken as objective measures of CFA or any indication of the ability of these teachers to use CFA in their own classrooms. It would be imprudent to say anything about the actual effectiveness of CFA methods with any measure of reliability that would tie the use of CFA to actual results; the inferences from the data observing opinions so overwhelmingly in favor CFA techniques only point to a need for further investigation.

The spirit of this research was in its contribution to the discussion on technology in education, best practices in formative assessment and their potential role in improving student retention in STEM courses. This study leaves me in want for more robust research into the potential merits of CFA techniques.

**Generalizability of Findings**

The stories in this study brought to the fore a comprehensive detailing of the value of cloud technologies not only in aiding regular evaluation of student learning but in their ability to change the way STEM courses are taught. However, the use of CFA techniques should in no way be limited to teaching in STEM disciplines. It’s difficult to think of a course of study where improvement in at least one of the student-focused learning ideals - *student engagement, motivation, accountability, metacognition, and collaboration* - would not be desired. For example, peer collaboration techniques discussed in this study
for the building of science teacher websites could also be extended to the writing classroom where students would review and edit each other’s work from home.

Recommendations

With the national push towards accountability, colleges and universities have been compelled to advance principles of assessment and to deliver confirmation of the efficacy of established educational programs. The result of this push has been an abundance of discussion concerning assessment of disciplined learning outcomes which are naturally summative. Such emphasis is fixed on assessment of learning “focused primarily on assigning grades as the principle indicator of student performance, in a teacher-directed manner” (Vonderwell, & Boboc, 2013, p. 23). The pedagogical insights given in this study promote the idea of assessment for learning which purposes to assist students by means of operative feedback. Such operative feedback endeavors to motivate students to achieve more personal involvement in the comprehension and absorption of knowledge and objectives they desire to achieve (Vonderwell, & Boboc, 2013; Herr, Rivas, Chang, Tippens, Vandergon, d'Alessio, & Nguyen-Graff, 2014; Elwood & Klenowski, 2002).

The strategic directions implementing new pedagogy relying on CFA techniques starts with commitment and objectives. The program should support and preserve such objectives as: providing quality educational experiences, increased retention of students in STEM disciplines, increased graduation of students in STEM disciplines, and professional development of faculty in the use of CFA methods. Beyond the meeting of department and university objectives, logistical questions and strategic planning regarding the implementation and use of educational technologies need to be addressed.
Such considerations include; the evaluation and updating of resources, defining and assessing effectiveness of the program, format adoption, boundaries for distance learning, and the costs of supporting the technologies.

Teachers in this study realized the benefits of the cloud-based strategies for formative assessment to stimulate student-centered learning. In most cases, teachers were eager to implement cloud-based CFA techniques. In many instances, available technology was a perceived barrier that kept teachers from the ability to realize the benefits of CFA. Where technology availability was not an issue, support for the technology was problematic. Reports show that teachers feel ineffective in their ability to apply new technologies in the classroom (Beaudrie & Boschmans, 2004; Bielema, 2000; Broussard, 2009; Griffin, 2003; Holmes, 2006; Latio, 2009; Blackmon, 2013). A 2013 study found peer mentoring and personal support (modeling) in the use of technology to be the two most effective methods in training teachers toward the successful implementation of technology in the classroom (Blackmon, 2013).

To realize the advantages of CFA techniques will require a commitment of support and sustainability from school leadership and administration. The development of technology infrastructure and professional development is crucial. In a discussion of early educational adaption of Apple’s iPad and other similar mobile-learning technologies (m-learning) at post-secondary institutions, Murphy (2011), observed that a substantial number of universities were engaged in uninformed piloting of the m-learning devices with a general notion that “we suspect this may be important, we just don’t know how yet” (p. 28). When a similar, less than supportive, poorly planned introduction of iPad’s was implemented by the LAUSD in 2013, undesirable consequences resulted in a
suspension of the 1.3 billion dollar program (L.A.Times, 2014). Institutional leadership would do well to communicate with educational product marketing representatives, internal IT departments and faculty to appreciate the support needs prior to implementing new technologies on campus.

In the interviews, it became apparent that many schools were resistant to emerging technologies. This may have been appropriate when considering that supportive infrastructure was not yet fully in place. More than one focus group interviewee noted that their school did not allow the students to use smartphones in class. This is also understandable when considering the inherent distractions smartphones embody. Yet, the educational potential in smartphone technologies is becoming so apparent that schools need to reconsider such constricting positions. In consideration of the cost savings considered in a readily available technology and the near complete lack of bureaucratic buy-in and accordance of teacher autonomy, it is time to realize and exploit the educational benefits of the smartphone.

The disappointing data on retention of STEM majors and non-majors enrolled in STEM courses along with the writings of Hewitt & Seymour (1997) suggest that student success in post-secondary institutions can be improved through effective formative assessment practices in the STEM classroom. With the suggestion found in this study that CFA techniques could constitute an improvement in the way formative assessment is executed and its potential in terms of assessment for learning, future studies should examine whether a direct relationship between CFA and improved retention exists and at what level of significance.
**Recommendations for future research.** Future research should involve a longitudinal quantitative approach to the research questions. While this overviewing study covered a general collection of available applications, studies focused on individual CFA techniques and their effect on student learning in both STEM and non-STEM classrooms would be beneficial. The use of CRS’s is well covered in the literature but there exists little discussion on classroom response technologies that allow for more varied free-form and illustrative input. Future discussion should emphasize the value of these techniques on developing pedagogy.

Dr. Vandergon’s perception that CFA techniques were most effective with students struggling in STEM courses recommends a need for supporting data. Future research with test and control groups of learners taught correspondingly with CFA and TFA methods would be of value in determining the actual potential of CFA with at-risk STEM students. Similarly, Dr. Nguyen-Graff believed that an increase rate of persistence among her class of non-major chemistry students could be due to her use of CFA techniques. Again, future investigation of her suggestion with quantitative data would be of importance in light of this study’s problem statements.

**Conclusion**

Formative assessment, in its most effective form, provides instructors an important visualization of their students’ cognizance. As the student-learning centered discussion in STEM fields proceeds, it is hopeful that STEM teachers bring themselves away from a strictly summative testing mindset that only shows what they didn’t know about what their students didn’t know. The methods of CFA hold great promise towards
that goal. This study serves as a preliminary study of participants' valuing of CFA and lays the foundation for justifying longitudinal, more robust research in this field.
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Appendix A: Interview Questions

Researcher: Marty Tippens  
Project Title: *The Effect of Computer Supported Continuous Formative Assessment on Student Learning in STEM Classrooms*

**Teaching**
1. What subjects do you teach?
2. Tell me about your experiences in trying to engage a STEM classroom.
3. Is there an advantage to pooling data for an experiment across classes? If so, explain.
4. Are you familiar with the Next Generation Science Standards (NGSS)? If so, explain.
5. The Dimension 1 of the NGSS focuses on improving student learning in the areas such as *asking questions, developing models, and interpreting data*. What advantages do you see in the use of cloud based technologies in achieving these standards?

**Technology**
1. I’d like to hear about your history with computer technology.
2. Describe how you’re experience with computer technologies found its way into your teaching. Where did you first experience technology in the classroom?
3. To what extent are students and teachers that you work with using cloud based tech at this time?
4. How did you Get Involved with the CSCS group? Why?

**FORMATIVE ASSESSMENT** Formative Assessment provides information concerning student engagement and learning during instruction so that teachers may adjust lessons to promote understanding and achievement.
1. What do you already know about formative assessment?
2. How long have you been using formative assessment to influence student learning?
3. Tell me how you have used it in your classrooms.
4. Did it help you in your classes? In what ways?
5. How did you apply traditional methods of formative assessment?
6. How have you applied cloud technologies in formative assessment?
7. When you teach STEM courses in the future, which if any technologies will you use?
8. How will you use them?
9. Suppose you had access to any technology in your classroom, which technologies would you use – if any – and how would you use them?
10. Would you encourage other teachers in your field to use formative assessment in general?

11. Would you encourage other teachers in your field to use technology in formatively assessing student learning? What advantages or disadvantages can you speak to?

12. Tell me a story about how you have used non-technology based formative assessment in the past and how it worked particularly well or not well.

13. Tell me a story about a time when you used cloud based technology to formatively assess a class and worked particularly well or not well.

14. What advantages of technology based formative assessment do you see over traditional methods of formative assessment?

15. What advantages of traditional formative assessment do you see over technology-based formative assessment?

Thank you for your time!
Appendix B: Pre-Survey

CSCS-pre-survey-Herr-525,514,619

You can include any text or info that will help people fill this out.

**First**
First Name

**Last**
Last Name

**Email**
Enter your gmail address

**Credentials**
Which credentials are you pursuing? Check all that apply
- [ ] Foundation level science
- [ ] Physics
- [ ] Chemistry
- [ ] Biology
- [ ] Geoscience
- [ ] Other: __________

**Subjects**
Which subject(s) do you plan to teach? Check all that apply.
- [ ] 6th - Earth Science
- [ ] 7th - Life Science
- [ ] 8th - Physical Science
- [ ] Physics (high school)
- [ ] Chemistry (high school)
- [ ] Biology (high school)
- [ ] Earth Science (High School)
- [ ] Non college preparatory science (High School)
- [ ] Other: __________
**Experience**
How many years have you been teaching?

**Skills**
Rate your confidence with the following:

<table>
<thead>
<tr>
<th></th>
<th>1 Not Confident</th>
<th>2 Low Confidence</th>
<th>3 Medium Confidence</th>
<th>4 Somewhat Confident</th>
<th>5 Highly Confident</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developing engaging activities that address California Science Standards</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Designing lessons to teach the nature of science</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Designing new science investigations</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Connecting science to other topics (math, history etc)</td>
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<td></td>
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</tr>
<tr>
<td>Collaborating with colleagues to develop resources for the classroom</td>
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<tr>
<td>Teaching science to English Language Learners</td>
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<tr>
<td>Assigning written work (e.g. essays, lab reports)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Assessing written work</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Having students evaluate large data sets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Technology**
Rate your confidence with these technologies:

<table>
<thead>
<tr>
<th></th>
<th>1 Don't know what that is</th>
<th>2 No confidence</th>
<th>3 Low confidence</th>
<th>4 Medium confidence</th>
<th>5 High confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creating online collaborative presentations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Using websites for instruction</td>
<td></td>
<td></td>
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<tr>
<td>Creating graphs from spreadsheets</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Creating online surveys</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collecting student work electronically</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Creating collaborative online drawings</td>
<td></td>
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</tbody>
</table>

https://docs.google.com/spreadsheet/viewform?key=0Au2p9YKpA13yCz2leTPV7It5dVEiS5USJC3aEa1IPN2z4&pli=1
Using collaborative documents
Sharing images and videos online

NOS
What is your understanding of the product and process (nature of science) of science at this point?

NOS-analysis
Rate your level of agreement with these statements about the nature of science (NOS)

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Unsure</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>The world is understandable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explaining and predicting are key components of science</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scientific knowledge is durable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scientific knowledge is tentative</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Science is mainly done in isolation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Science can be subjective</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>There is bias in the scientific enterprise</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>All questions can be answered through science</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>There is a single method for conducting science</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Science requires being logical and systematic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Science requires being creative and imaginative</td>
<td></td>
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</tr>
</tbody>
</table>

Qualities
What are the most important qualities needed for being a scientist?

https://docs.google.com/spreadsheets/d/1Ux2yYKj1pJa3Y10D2eTPv72bV6E8SU5J03HeaT1Pv2o/edit#gid=0
### Future plans *

When you teach science in the future, how often do you think you will employ the following teaching strategies during your science lessons?

<table>
<thead>
<tr>
<th>Strategy</th>
<th>never</th>
<th>a few times a year</th>
<th>once or twice a month</th>
<th>once or twice a week</th>
<th>almost every day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Online presentations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Educational websites</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Websites you have developed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student analysis of entire class data</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electronic surveys</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photos taken for instructional purposes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Videos of activities done in class</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Electronic mapping resources</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Online posting of assignments, homework or grades</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Electronic quickwrites</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Collaborative online documents</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Collaborative online presentations</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Collaborative online drawings</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Collaborative online spreadsheets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collaborative maps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Online peer feedback</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Wikis which allow student input</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analysis of personal data</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Analysis of lab group data</td>
<td></td>
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<td></td>
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<tr>
<td>Analysis of entire class data</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Analysis of data from multiple classes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Pooling data

https://docs.google.com/spreadsheet/ forma?...
FORMATIVE ASSESSMENT

Formative Assessment provides information concerning student engagement and learning during instruction so that teachers may adjust lessons to promote understanding and achievement.

Formative Assessment - knowledge *
What do you already know about formative assessment?

Formative Assessment - practice *
In what ways have you used formative assessment prior to this class?

Formative Assessment - practice *
If you have used formative assessment techniques in your class, have you found them to be effective? In what ways?

Formative Assessment - Frequency *
The following are techniques for formative assessment. Approximately how often did you encounter these in your own experience as a high school student in science classes?

<table>
<thead>
<tr>
<th>Technique</th>
<th>Never</th>
<th>Yearly</th>
<th>Monthly</th>
<th>Weekly</th>
<th>Daily</th>
</tr>
</thead>
<tbody>
<tr>
<td>HANDS RAISED; HAND SIGNALS - Ask students to display a designated hand signal to indicate their understanding of a specific concept, principle, or process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ONE MINUTE ESSAY - A one-minute essay question (or one-minute question) is a focused question with a specific goal that can, in fact, be answered within a minute or two.</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

https://docs.google.com/spreadsheet/ctlRisk?key=0Au2prYKipA13ryZ2IkTFV72d6VE85U5K0Zcosa1IP20cd&gridid=5ledt  5/8
<table>
<thead>
<tr>
<th>Activity Description</th>
<th>Checkbox</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANALOGY PROMPT - Periodically, present students with an analogy prompt: (A designated concept, principle, or process) is like because</td>
<td></td>
</tr>
<tr>
<td>WEB OR CONCEPT MAP - Any of several forms of graphical organizers which allow learners to perceive relationships between concepts through diagramming key words representing those concepts.</td>
<td></td>
</tr>
<tr>
<td>STUDENT CONFERENCE - One on one conversation with students to check their level of understanding.</td>
<td></td>
</tr>
<tr>
<td>OBSERVATION - Walk around the classroom and observe students as they work to check for learning. Strategies include: Anecdotal Records, Conferences, Checklists</td>
<td></td>
</tr>
<tr>
<td>SELF-ASSESSMENT - A process in which students collect information about their own learning, analyze what it reveals about their progress toward the intended learning goals and plan the next steps in their learning.</td>
<td></td>
</tr>
<tr>
<td>EXIT CARD - Exit cards are written student responses to questions posed at the end of a class or learning activity or at the end of a day.</td>
<td></td>
</tr>
<tr>
<td>PORTFOLIO CHECK - Check the progress of a student's portfolio. A portfolio is a purposeful collection of significant work, carefully selected, dated and presented to tell the story of a student's achievement or growth in well-defined areas of performance, such as reading, writing, math, etc. A portfolio usually includes personal reflections where the student explains why each piece was chosen and what it shows about his/her growing skills and abilities.</td>
<td></td>
</tr>
<tr>
<td>QUIZ - Quizzes assess students for factual information, concepts and discrete skill. There is usually a single best answer.</td>
<td></td>
</tr>
<tr>
<td>JOURNAL ENTRY - Students record in a journal their understanding of the topic, concept or lesson taught. The teacher reviews the entry to see if the student has gained an understanding of the topic, lesson or concept that was taught.</td>
<td></td>
</tr>
<tr>
<td>CHORAL RESPONSE - In response to a cue, all students respond verbally at the same time. The response can be either to answer a question or to repeat something the teacher has said.</td>
<td></td>
</tr>
<tr>
<td>A-B-C SUMMARIES - Each student in the class is assigned a different letter of the alphabet and they must select a word starting with that letter that is related to the topic being studied.</td>
<td></td>
</tr>
<tr>
<td>DEBRIEFING - A form of reflection immediately following an activity.</td>
<td></td>
</tr>
<tr>
<td>AUDIENCE RESPONSE SYSTEM - Hand-held &quot;clickers&quot; to which students can respond to teacher prompts.</td>
<td></td>
</tr>
<tr>
<td>ELECTRONIC QUICKWRITE - An collaborative cloud-based document to which students post responses to teacher prompts.</td>
<td></td>
</tr>
</tbody>
</table>
Formative Assessment - Your plans *
How often do you think you will use these in the teaching of your own classes, knowing what you know today. Be realistic.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Never</th>
<th>Yearly</th>
<th>Monthly</th>
<th>Weekly</th>
<th>Daily</th>
</tr>
</thead>
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<td></td>
<td></td>
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<td></td>
<td></td>
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<td>PORTFOLIO CHECK - Check the progress of a student's portfolio. A portfolio is a purposesful collection of significant work, carefully selected, dated and presented to tell the story of a student's achievement or growth in well-defined areas of performance, such as reading, writing, math, etc. A portfolio usually includes personal reflections where the student explains why each piece was chosen and what it shows about higher growing skills and abilities.</td>
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<tr>
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</tr>
<tr>
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</tbody>
</table>

https://docs.google.com/spreadsheets/d/13yD2kEFPyl2s6tvX885USU3OeYa7IP2o5g/edit#gid=664721632
<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEBRIEFING</td>
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</tr>
<tr>
<td>AUDIENCE RESPONSE</td>
<td>Hand-held “clickers” to which students can respond to teacher prompts.</td>
</tr>
<tr>
<td>ELECTRONIC QUICKWRITE</td>
<td>An collaborative cloud-based document to which students post responses to teacher prompts.</td>
</tr>
</tbody>
</table>
Appendix C: Formative Assessment Survey

Formative Assessment Survey

Formative assessment is a process used by teachers and students during instruction that provides feedback to adjust ongoing teaching and learning. It is intended to improve students' achievement of instructional outcomes. Both the instructor and students use formative assessment data to improve learning. CSUN's Computer Supported Collaborative Science (CSCS) consortium (csunscience.com) has developed a teaching technique that employs synchronous collaborative web-based tools to perform continuous, real-time formative assessments of student understanding so that science teachers can adjust their instruction to address the immediate needs of their students. Using this model, teachers obtain immediate evidence of student understanding through instantaneous collection of text, graphic and multi-media artifacts, enabling them to adjust instruction to maximize learning.

* Required

Confidentiality Statement

This survey guarantees respondent confidentiality. The survey responses will not be integrated, analyzed, or reported in any way in which the confidentiality of the survey responses is not absolutely guaranteed.

All survey responses will be transferred to a secure, password-restricted server. Access to raw data will be tightly restricted to only those individuals directly involved in data analysis. Distribution and/or reproduction of any record or information outside the intended and approved use is strictly prohibited.

Your participation in this research study is voluntary. You may choose not to participate and you may withdraw your consent to participate at any time. You will not be penalized in any way should you decide not to participate or to withdraw from this study.

1. First Name *
   We need your name so that we get complete but not repetitive data.

2. Last Name *

DEFINITION OF TERMS

CFA (CONTINUOUS FORMATIVE ASSESSMENT)
Continuous Formative Assessment (CFA) employs cloud-based collaborative document technology to instantly collect responses from multiple students, groups, and class sections. CFA includes such techniques as Quick-writes, collaborative data tables, surveys, scan & post, collaborative text, collaborative presentations, submit & vote, classroom response system, and collaborative drawing/mapping.
TRADITIONAL FORMATIVE ASSESSMENT
Traditional formative assessment includes techniques such as hand raising; one-minute essay, student conferences, whiteboards, observations, exit cards, quizzes, journal entries, and choral responses.

YOUR EXPERIENCES AS A CSUN STUDENT

IMPORTANT - For the following questions, please reflect on your experiences as a college student in courses in which continuous formative assessment (CFA) is/was employed in contrast to other college courses in which CFA is/was not employed.

3. Continuous Formative Assessment (CFA)
Where have you learned about CFA? Check all that apply
Check all that apply.

☐ Masters Degree Program (Science Education)
☐ Masters Degree Program (Educational Technology)
☐ Credential Program
☐ Summer Institute (California Science Project - CSCS Summer Workshops)
☐ Project GRAD LA

4. CSUN Classes
In which CSUN courses have you been exposed to CFA (Formative Assessment aspect of CSCS). Check all that apply
Check all that apply.

☐ 514 (Computers in Instruction)
☐ 525S (Methods of Teaching Science)
☐ 554 (Supervised Field Experience in Teaching Science)
☐ 555 (Student Teaching in Science - 2nd semester)
☐ 619 (Educational Website Development)
☐ 646 (Computers in Math and Science)
☐ 666b (Advanced Science Laboratory Development)
☐ 666G (Computer Supported Collaborative Learning CSCL)
☐ Other: ____________________________________________________________
5. Tools you have used as a CSUN student
Which CFA tools have you employed to assess student understanding?
Check all that apply.

☐ Quick-write (recording student ideas using a collaborative spreadsheet)
☐ Collaborative data table (collecting, graphing & analyzing pooled data)
☐ Surveys (contributing data using a form; e.g. Google forms)
☐ Scan & Post (using smartphone to record & upload diagrams, drawings & photos)
☐ Collaborative Text (writing a document synchronously with others; e.g. Google doc)
☐ Collaborative Presentation (contributing to a collaborative presentation; e.g Google presentations)
☐ Submit & Vote (ranking student questions & responses; e.g. Moderator, Poll Anywhere; peer voting)
☐ Classroom Response System (answering pre-made questions; e.g. clickers, Socrative)
☐ Collaborative Drawing / Mapping (creating an online drawing, diagram, or map; e.g. Google drawings, Collaborate Whiteboard)
☐ Other: __________________________________________________________

6. Awareness of my own thought processes
How much do you think about your own strategies for answering questions or solving problems in courses using CFA versus other courses where CFA is not employed?
Mark only one oval.

☐ I am much more conscious of my thought processes and problem solving strategies
☐ I am more conscious of my thought processes and problem solving strategies
☐ I don't see any difference
☐ I am less conscious of my thought processes and problem solving strategies
☐ I am much less conscious of my thought processes and problem solving strategies

7. Asking myself further exploratory questions
How likely are you to ask yourself further exploratory content-related questions in courses using CFA versus other courses where CFA is not employed?
Mark only one oval.

☐ I am much more likely to ask myself further exploratory questions
☐ I am more likely to ask myself further exploratory questions
☐ I don't see any difference
☐ I am less likely to ask myself further exploratory questions
☐ I am much less likely to ask myself further exploratory questions
8. **Awareness of alternative problem solving strategies**
   How aware are you of alternative approaches to solving problems in courses using CFA versus other courses where CFA is not employed?
   *Mark only one oval.*
   - I am much more conscious of alternative problem solving strategies
   - I am more conscious of alternative problem solving strategies
   - I don't see any difference
   - I am less conscious of alternative problem solving strategies
   - I am much less conscious of alternative problem solving strategies

9. **Awareness of various ways to interpret data**
   How aware are you of alternative interpretations of evidence in courses using CFA versus other courses where CFA is not employed?
   *Mark only one oval.*
   - I am much more aware of alternative interpretations of evidence
   - I am more aware of alternative interpretations of evidence
   - I don't see any difference
   - I am less aware of alternative interpretations of evidence
   - I am much less aware of alternative interpretations of evidence

10. **Awareness of alternative perspectives**
    How aware are you of alternative perspectives (viewpoints) in courses using CFA versus other courses where CFA is not employed?
    *Mark only one oval.*
    - I am much more aware of alternative perspectives
    - I am more aware of alternative perspectives
    - I don't see any difference
    - I am less aware of alternative perspectives
    - I am much less aware of alternative perspectives

11. **Self-monitoring as a learner**
    CFA allows you to see data from your peers. How likely are you to recognize your errors in courses using CFA versus other courses where CFA is not employed?
    *Mark only one oval.*
    - I am much more likely to recognize my errors when I see data from my peers
    - I am more likely to recognize my errors when I see data from my peers
    - I don't see any difference
    - I am less likely to recognize my errors when I see data from my peers
    - I am much less likely to recognize my errors when I see data from my peers

https://docs.google.com/forms/d/1G7qoJvOvZKUDhQOuYGwemIN6IY3Qp_HLqLuM0d44edt1
12. **Learning from peers**
How often have you gained insights from your classmates in courses using CFA versus other courses where CFA is not employed?

Mark only one oval.

- I learn much more from my peers
- I learn more from my peers
- I don't see any difference
- I learn less from my peers
- I learn much less from my peers

13. **Accountability to instructor during instruction**
How accountable do you feel to contribute/participate during class in courses using CFA versus other courses where CFA is not employed?

Mark only one oval.

- I feel much more accountable to the instructor
- I feel more accountable to the instructor
- I don't see any difference
- I feel less accountable to the instructor
- I feel much less accountable to the instructor

14. **Accountability for my own learning**
How responsible do you feel for your own learning in courses using CFA versus other courses where CFA is not employed?

Mark only one oval.

- I feel much more accountable for my own learning
- I feel more accountable for my own learning
- I don't see any difference
- I feel less accountable for my own learning
- I feel much less accountable for my own learning

15. **Accountability to peers during instruction**
How much do you feel like a team-member in courses using CFA versus other courses where CFA is not employed?

Mark only one oval.

- I feel much more accountable to my peers
- I feel more accountable to my peers
- I don't see any difference
- I feel less accountable to my peers
- I feel much less accountable to my peers
16. Engagement during Instruction
   What is your personal level of involvement during instruction in courses using CFA versus other courses where CFA is not employed?
   Mark only one oval.
   - I am much more engaged during instruction
   - I am more engaged during instruction
   - I don't see any difference
   - I am less engaged during instruction
   - I am much less engaged during instruction

17. Asking questions in class
   How likely are you to ask questions (posting online and/or raising your hand) in courses using CFA versus other courses where CFA is not employed?
   Mark only one oval.
   - I am much more likely to ask questions
   - I am more likely to ask questions
   - I don't see any difference
   - I am less likely to ask questions
   - I am much less likely to ask questions

18. Likelihood of my ideas being recognized by the instructor
   How likely are you to have your ideas verbally recognized by the instructor in comparison with other college classes where CFA is not employed?
   Mark only one oval.
   - I am much more likely to have my ideas verbally recognized by the instructor
   - I am more likely to have my ideas verbally recognized by the instructor
   - I don't see any difference
   - I am less likely to have my ideas verbally recognized by the instructor
   - I am much less likely to have my ideas verbally recognized by the instructor

19. Benefits of CFA as a student
   Please describe any benefits of participating in a class in which CFA is employed. Please be specific and as detailed as possible. (If no benefits, state “none”)

https://docs.google.com/forms/d/1G77pNYCwA2ZBUJZnOuYeBKkwiNjiG9y34p_JLqJtwM294Hed1/edit

6/18
20. **Have you used CFA in your own teaching?**
Have you ever employed Continuous Formative Assessment techniques as a teacher or student teacher?
Mark only one oval.

☐ yes  
Skip to question 28.

☐ no

**QUESTIONS FOR TEACHERS WHO HAVE NOT USED CFA IN THE CLASSROOM**
State your level of agreement with the following statements with respect to the potential use of CFA as compared with traditional forms of formative assessment. Assume that you have the technology and resources necessary for both. See definitions below.

**CFA (CONTINUOUS FORMATIVE ASSESSMENT)**
Continuous Formative Assessment (CFA) employs cloud-based collaborative document technology to instantly collect responses from multiple students, groups, and class sections. CFA includes such techniques as Quick-writes, collaborative data tables, surveys, scan & post, collaborative text, collaborative presentations, submit & vote, classroom response system, and collaborative drawing/mapping.

**TRADITIONAL FORMATIVE ASSESSMENT**
Traditional formative assessment includes techniques such as hand raising; one-minute essay, student conferences, whiteboards, observations, exit cards, quizzes, journal entries, and choral responses.

Skip to question 35.
21. **Potential use of CFA in your classrooms**

Assuming that you had the necessary technologies, how many days per month would you use Continuous Formative Assessment (CFA) in your classroom?

*Mark only one oval per row.*

<table>
<thead>
<tr>
<th></th>
<th>16 or more (most days)</th>
<th>6-15 (about a few times a week)</th>
<th>3-5 (about once per week)</th>
<th>1-2 (about every other week)</th>
<th>0 (never)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quick-write</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Collaborative data table</td>
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<td></td>
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<tr>
<td>Surveys</td>
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<tr>
<td>Scan &amp; Post</td>
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<tr>
<td>Collaborative Text</td>
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<tr>
<td>Collaborative Presentation</td>
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<tr>
<td>Submit &amp; Vote</td>
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<tr>
<td>Classroom Response System</td>
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<tr>
<td>Collaborative Drawing / Mapping</td>
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</tbody>
</table>
22. **Predicted level of awareness of student cognition and behavior**
   
   Compare the predicted effectiveness of CFA vs traditional methods of formative assessment with respect to the following...

   *Mark only one oval per row.*

<table>
<thead>
<tr>
<th></th>
<th>Traditional methods would be much more effective</th>
<th>Traditional methods would be more effective</th>
<th>No difference</th>
<th>CFA would be more effective</th>
<th>CFA would be much more effective</th>
</tr>
</thead>
<tbody>
<tr>
<td>My awareness of the level of student engagement</td>
<td>[ ]</td>
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<td>[ ]</td>
</tr>
<tr>
<td>My awareness of the level of student understanding</td>
<td>[ ]</td>
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</tr>
<tr>
<td>My awareness of student misconceptions</td>
<td>[ ]</td>
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<td>[ ]</td>
</tr>
</tbody>
</table>
23. **Predicted effect of CFA on student learning**

Compare your predicted effect of CFA vs traditional methods of formative assessment at promoting these NGSS learning goals:

*Mark only one oval per row.*

<table>
<thead>
<tr>
<th></th>
<th>Traditional methods would be much more effective</th>
<th>Traditional methods would be more effective</th>
<th>No difference</th>
<th>CFA would be more effective</th>
<th>CFA would be much more effective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asking questions</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Developing and using models</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
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<tr>
<td>Planning and carrying out investigations</td>
<td>☐</td>
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<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Analyzing and interpreting data</td>
<td>☐</td>
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<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Using mathematics and computational thinking</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Constructing explanations or solutions</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
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</tr>
<tr>
<td>Engaging in argument from evidence</td>
<td>☐</td>
<td>☐</td>
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<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Obtaining, evaluating, and communicating information</td>
<td>☐</td>
<td>☐</td>
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</tr>
</tbody>
</table>
24. **Predicted Effect of CFA on student motivation**

Compare your predictions of student motivation when using CFA vs traditional methods of formative assessment.

*Mark only one oval per row.*

<table>
<thead>
<tr>
<th>Traditional methods would be much more effective</th>
<th>Traditional methods would be more effective</th>
<th>No difference</th>
<th>CFA would be more effective</th>
<th>CFA would be much more effective</th>
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</thead>
<tbody>
<tr>
<td>Recognizing value of task (Understanding purpose of activity)</td>
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<tr>
<td>Fostering self-efficacy (Feeling that they will be successful in the task)</td>
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<tr>
<td>Willingness to complete tasks</td>
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</tbody>
</table>

25. **Predicted adjustments to instruction**

Compare your likeliness to make the following adjustments to instruction when using CFA vs traditional methods of formative assessment.

*Mark only one oval per row.*

<table>
<thead>
<tr>
<th>Much more likely with traditional methods</th>
<th>More likely with traditional methods</th>
<th>No difference</th>
<th>More likely with CFA</th>
<th>Much more likely with CFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Providing additional examples</td>
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<tr>
<td>Adjusting the pace of instruction</td>
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<tr>
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<tr>
<td>Repeating a concept to insure understanding</td>
<td></td>
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</tr>
</tbody>
</table>
26. Predicted benefits of CFA as a teacher
Please describe any predicted benefits of using CFA while teaching. Please be specific and as detailed as possible. (If no benefits, state "none")

27. Predicted problems of CFA as a teacher
Please describe any predicted problems of using CFA while teaching. Please be specific and as detailed as possible. (If no problems, state "none")

QUESTIONS FOR TEACHERS WHO HAVE USED CFA IN THE CLASSROOM

State your level of agreement with the following statements with respect to the use of CFA as compared with traditional forms of formative assessment. Assume that you have the technology and resources necessary for both. See definitions below.

CFA (CONTINUOUS FORMATIVE ASSESSMENT)
Continuous Formative Assessment (CFA) employs cloud-based collaborative document technology to instantly collect responses from multiple students, groups, and class sections. CFA includes such techniques as Quick-writes, collaborative data tables, surveys, scan & post, collaborative text, collaborative presentations, submit & vote, classroom response system, and collaborative drawing/mapping.

TRADITIONAL FORMATIVE ASSESSMENT
Traditional formative assessment includes techniques such as hand raising; one-minute essay, student conferences, whiteboards, observations, exit cards, quizzes, journal entries, and chorale responses.

Skip to question 35.
28. Tools you have used as a teacher
Which CFA Tools have you employed to assess student understanding?
Check all that apply:
- Quick-write (recording student ideas using a collaborative spreadsheet)
- Collaborative data table (collecting, graphing & analyzing pooled data)
- Surveys (contributing data using a form; e.g. Google forms)
- Scan & Post (using smartphone to record & upload diagrams, drawings & photos)
- Collaborative Text (writing a document synchronously with others; e.g. Google doc)
- Collaborative Presentation (contributing to a collaborative presentation; e.g Google presentations)
- Submit & Vote (ranking student questions & responses; e.g. Moderator, Poll Anywhere; peer voting)
- Classroom Response System (answering pre-made questions; e.g. clickers, Socrative)
- Collaborative Drawing / Mapping (creating an online drawing, diagram, or map; e.g. Google drawings, Collaborate Whiteboard)

29. Awareness of student cognition and behavior
Compare the effectiveness of CFA vs traditional methods of formative assessment with respect to the following...
*Mark only one oval per row.*

<table>
<thead>
<tr>
<th>Traditional methods are much more effective</th>
<th>Traditional methods are more effective</th>
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<tbody>
<tr>
<td>My awareness of the level of student engagement</td>
<td>![ ]</td>
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<td>![ ]</td>
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<tr>
<td>My awareness of the level of student understanding</td>
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</tr>
<tr>
<td>My awareness of student misconceptions</td>
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</table>

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30. **Effect of CFA on student learning**

Compare your perception of CFA vs traditional methods of formative assessment at promoting these NGSS learning goals:

*Mark only one oval per row.*

<table>
<thead>
<tr>
<th></th>
<th>Traditional methods are much more effective</th>
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<tr>
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<tr>
<td>Engaging in argument from</td>
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<td>evidence</td>
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<td>Obtaining, evaluating, and</td>
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<td>communicating information</td>
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</tbody>
</table>
31. **Perceived Effect of CFA on student motivation**

Compare your perception of student motivation when using CFA vs traditional methods of formative assessment.

*Mark only one oval per row.*

<table>
<thead>
<tr>
<th>Traditional methods are much more effective</th>
<th>Traditional methods are more effective</th>
<th>No difference</th>
<th>CFA is more effective</th>
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<tr>
<td>Recognizing value of task (Understanding purpose of activity)</td>
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<tr>
<td>Willingness to complete tasks</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
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</tbody>
</table>

32. **Adjustments to Instruction**

Compare your likelihood to make the following adjustments to instruction when using CFA vs traditional methods of formative assessment.

*Mark only one oval per row.*

<table>
<thead>
<tr>
<th>Much more likely with traditional methods</th>
<th>More likely with traditional methods</th>
<th>No difference</th>
<th>More likely with CFA</th>
<th>Much more likely with CFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Providing additional examples</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Adjusting the pace of instruction</td>
<td>☐</td>
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<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Adjusting the sequence of instruction</td>
<td>☐</td>
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<tr>
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</tr>
<tr>
<td>Repeating a concept to ensure understanding</td>
<td>☐</td>
<td>☐</td>
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<td>☐</td>
</tr>
</tbody>
</table>
33. **Potential use of CFA in your classrooms**
   Assuming that you had the necessary technologies, how many days per month would you use Continuous Formative Assessment (CFA) in your classroom?
   
   *Mark only one oval per row.*

<table>
<thead>
<tr>
<th>16 or more (most days)</th>
<th>6-15 (about a few times a week)</th>
<th>3-5 (about once per week)</th>
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<tbody>
<tr>
<td>Quick-write</td>
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<tr>
<td>Collaborative data table</td>
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<tr>
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</tr>
<tr>
<td>Collaborative Drawing / Mapping</td>
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</tr>
</tbody>
</table>

34. **Benefits of CFA as a teacher**
   Please describe any benefits of teaching a class in which CFA is employed. Please be specific and as detailed as possible. (If no benefits, state “none”)

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**SUMMARY**

*Skip to question 35.*
35. Which best describes your teaching experience?
Mark only one oval.
☐ Pre-service teacher
☐ Student teacher
☐ Teacher (1-3 years experience)
☐ Teacher (4 or more years experience)
☐ Other: ____________________________________________

36. Teaching
What courses do you teach or intend to teach? Check all that apply
Check all that apply.
☐ Science
☐ Mathematics
☐ Computer Technology
☐ English / Language Arts
☐ Social Studies
☐ Performing and Visual Arts
☐ Other: ____________________________________________

37. School
What level do you teach or intend to teach?
Mark only one oval.
☐ college
☐ high school
☐ middle school
☐ elementary school
☐ Other: ____________________________________________
38. **Computer/tablet ratio**
What is the ratio of computers and/or tablets to students in the classroom in which you teach?

- [ ] I am not teaching
- [ ] 1:1
- [ ] 1:2
- [ ] 1:3
- [ ] 1:4
- [ ] less than 1:4
- [ ] only instructor has a computer/tablet
- [ ] there are no computers in classroom
- [ ] students supply their own technology (laptops, tablets, smartphones)
- [ ] Other: ____________________________

39. **Explain why you would choose or not choose to use CFA**
Assuming that you have access to the technologies necessary for Continuous Formative Assessment (CFA), give reasons why you would choose to use CFA or not use CFA.

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Appendix D: Coding List for Qualitative interviews on CFA and Formative Assessment

I. Events and Activities
   1. Classes
      a.  STEM related
      b.  Non-STEM related
   2. Early experiences with Formative Assessment
      a.  At elementary school
      b.  At middle school
      c.  In high school
      d.  In post-secondary education

II. Attitudes
   1. Towards Technology
      a.  Positive, always liked tech in the classroom, still do.
      b.  Ambiguous, could take it or leave it.
      c.  Negative, always hated it
      d.  Misunderstanding of uses of technology in the classroom
      e.  Fear of
      f.  No fear of
   2. Agency
      a.  Awareness of how to negotiate the system
      b.  Clear sense of future goals
      c.  Ownership of one’s learning
         i.  Low: Lack of – expecting to be taught
         ii. High: Personally responsible for material learned.
   3. The role of teachers
      a.  In touch with students
      b.  Out of touch with students
   4. Towards STEM subjects
      a.  Positive
      b.  Negative

III. Reflection
   1. My reflection as an interviewer
   2. Adult Experiences in Formative Assessment
      a.  In the classroom
      b.  In daily life
   3. Childhood experiences with Formative Assessment
      a.  In the classroom
b. In daily life

4. Telling Statements – things said that say more than was clearly intended

IV. Teaching Methods
   a. Authentic – giving real life experiences
   b. Lecture
   c. Discussion

V. Learning Methods
   a. Collaborative
   b. Integrated

VI. Formative assessment
   ▪ Techniques
     • Hand raising
     • One Minute Essay
     • Analogy Prompt
     • Concept Map
     • Student conference
     • Observation
     • Self-Assessment
     • Exit Card
     • Portfolio Check
     • Quiz
     • Journal Entry
     • Choral Response
     • Audience Response System (clickers)
     • Electronic Quick Write
   ▪ Effect on learner
     • Self-efficacy
     • Accountability
     • Metacognition
     • Collaboration
     • Engagement
     • Motivation
   ▪ Effect on teaching
     • Enlightenment towards student understanding or misconceptions
     • Adjustment – teacher adjusts teaching as a result of student responses.
Appendix E: Chapter in “Assessment in Online and Blended Learning Environments”


Assessment in Online and Blended Learning Environments

Continuous Formative Assessment (CFA) During Blended and Online Instruction using Cloud-Based Collaborative Documents

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Abstract
This chapter describes the Continuous Formative Assessment (CFA) model for utilizing cloud-based collaborative document technology to instantly collect responses from multiple students, groups, and class sections. Utilizing CFA, instructors can collect student response data from large sets of students across groups or classes and analyze them quickly and accurately. Instructors of online and blended learning courses can employ CFA strategies to enhance student engagement and monitor student understanding during synchronous online or in-person instruction. As instructors analyze student responses, instruction adjustments can be made to meet immediate student needs. This chapter introduces specific instructional strategies that may be employed to increase the accountability and involvement of students in online settings. Preliminary data suggests that the CFA methodology promotes engagement, accountability, and understanding through formative assessment for both students and instructors.

Introduction
Blended and online learning environments provide instructors with significant challenges regarding the engagement and assessment of learners. How can teachers engage learners and assess their understanding in remote settings? Furthermore, how can instructors perform formative assessment to adjust their instruction to meet the immediate needs of distant learners? The Continuous Formative Assessment (CFA) model helps teachers create an environment that engages learners and provides opportunities for instructors to monitor student progress through continuous formative assessments so they can modify instruction to maximize learning in blended and online environments.

Schools and universities have been encouraged to develop a “culture of assessment” to provide evidence on the effectiveness of instructional programs (Weiner, 2009). Although the emphasis on assessment has produced a wealth of literature, legislation, initiatives, reforms, and professional development, the vast majority has focused on assessment of learning (summative assessment) rather than assessment for learning (formative assessment). Formative assessment is generally defined as a process used by teachers that provides feedback by which they can adjust ongoing teaching and learning to improve achievement during the process of instruction (Popham, 2008). What makes formative assessment ‘formative’ is that it is immediately used to make adjustments to instruction to meet the needs of the learners during the construction of understanding (Shepard, 2005).

Formative assessment is not a new concept, and any teacher who adjusts his or her teaching during instruction on the basis of evidence of student understanding and performance is employing formative assessment (Popham, 2008; Shepard, 2005). Traditional formative assessment techniques such as student questioning or quizzes are limited in how many students are assessed or can be difficult to analyze during class. The challenge is even greater in online environments were there is limited interaction with students. How does one accurately assess student comprehension and performance during a class session, particularly in blended and online settings?

A promising response to this question is found in new collaborative cloud-based document technologies. Such technologies provide the opportunity to instantly collect and analyze large sets of data from multiple students, groups and class sections with speed and accuracy, regardless of the physical location of students. The CFA instructional model employs these technologies to create environments that mirror collaborative professional research communities in which colleagues evaluate each other’s work and ideas on a continual basis. Similarly, teachers create blended and online classroom activities in which students analyze whole-class data using collaborative cloud-based spreadsheets, documents, wikis and presentations. These activities help students gain an understanding that the learning enterprise requires collaboration, independent verification, and peer review. This chapter will introduce a range of collaborative cloud-based activities through which educators can continuously monitor student ideas and adjust their instructional practice to enhance student learning.

**Literature Review / Conceptual Framing**

To understand *formative assessment* and its role in online and blended instruction, it is helpful to contrast it with *summative* and *interim assessments*. *Summative assessments*
are generally “high-stakes” tests that are used to determine student grades and class-wide or school-wide performance. Summative assessments are used to measure mastery of predetermined content or standards and are the backbone of accountability systems at all academic levels. Student grades, college admission, scholarships, graduation, and school rankings are all determined primarily by summative assessments. Summative assessments play a critical role in accountability systems and inform local, statewide, and national educational policies (Perie, Gong, & Wurtzel, 2007).

Although summative assessments are invaluable for accountability, they cannot be used to diagnose gaps between student knowledge and the intended curriculum at a time when instructional adjustments can be made to benefit student learning. Summative assessments inform stakeholders concerning what students did or did not learn, but do not provide information that will change instruction to benefit current students. Educators therefore employ interim assessments throughout instruction to provide such information. Interim assessments, also known as medium cycle assessments, are administered throughout a course to provide information to diagnose problems and provide information on how instruction can be changed to best meet student needs. Interim assessments take many forms, such as quizzes and reports, and may factor into final grades and school or system assessments. Interim assessments provide students with practice for summative tests and provide teachers with information necessary to adjust future instruction (Perie et al., 2007; Pinchok & Brandt, 2009).

Although summative and interim assessments provide invaluable information and help establish an environment of accountability, they do not provide instructors or students with the information necessary to improve teaching and learning during the actual instruction. By contrast, formative assessments are embedded in instruction and are directly linked to teaching and learning as it occurs. Formative assessments identify gaps in understanding and can be used by teachers and students to make adjustments to improve student learning as it occurs. Formative assessments can be frequent and provide teachers and students with timely feedback on progress (Black & Wiliam, 1998; Black & Wiliam, 2009; Shepard, 2005).

There is much research to show that formative assessments can be used to improve student learning success. Meta-studies analyzing the findings of numerous investigators concluded that formative assessments provide “moments of contingency” (Black & Wiliam, 2009, p. 10), critical points where learning changes direction depending on an assessment. Well-designed formative assessments provide information to make instructional modifications in real-time to address student needs (Black & Wiliam, 2009; Shepard, 2005). There are numerous techniques that can be used for formative assessment including hand raising (in response to specific questions), hand signals (to measure levels of self-reported understanding), choral responses (in which students are invited to respond simultaneously to teacher-posed questions), think-pair-share (in which teachers assess student understanding as student groups share with the class), quick-writes (in which students make journal entries in response to specific prompts), exit cards (in which students submit questions or answers as they leave class), self-assessments (in which students check their own understanding by working problems or answering questions in class) and quizzes (in which teachers pose questions to test student
understanding) (Stull, Majerich, Bernacki, Jansen, Varnum, & Ducette, 2011; Fluckiger, Vigil, Pasco, & Danielson, 2010; Jahan, Shaikh, Norrish, Siddqi, & Qasim, 2013; Youssef, 2012). All of these techniques have proven valuable in traditional classroom settings but many of these still do not provide the instructor with an immediate assessment of student needs.

For example, the instructor gathers cards and reads them after class or grades quizzes after class.

Formative assessments have been shown to be particularly valuable with lower performing students. Learning deficiencies can be identified early in the learning cycle, allowing instructors to make teaching modifications before lower performing students are left behind (Athanases & Achinstein, 2003). Numerous textbook publishers produce online quizzes to provide students and instructors immediate feedback, and such products can be very effective in helping identify gaps in students’ understanding (Hoon, Chong & Ginti Ngah, 2010). Formative assessment is an iterative “joint productive activity” in which students assemble and interpret knowledge and present their understanding to their teachers who then adjust instruction to optimize learning. This process is repeated throughout learning units (Ash & Levitt, 2003).

Bandura (1997) and Zimmerman (2002) suggested that formative assessments permit students to express themselves and develop a sense of self-efficacy, a key requirement for the development of autonomous learning strategies. Polanyi (1967) and Schön (1987) emphasized the formative and reflective purpose of student discourse and encourage an open community of learners where ideas and opinions are exchanged so that students can co-construct their understanding. The CFA model provides an environment where such discourse can take place, but unlike traditional instruction where certain students dominate and others are passive, all students are on an equal footing since all have access to the same document for their contributions. A discussion of the underlying theories on which the CFA model is built as well as practical instruction for implementation and findings from ongoing research follows.

**Formative Assessment and Technology**

Online education has grown dramatically in recent years and is expected to continue growing in the years to come. In his State of the Union address, President Obama suggested that technology will play an increasingly significant role in America’s plan to increase the number college graduates while decreasing the cost of education (Obama, 2010). The President encouraged the growth of online education to attract more students to college, particularly those from populations under-represented on traditional brick-and-mortar campuses (Sturgis, 2012). The growth of online and blended education has been accompanied by a growing concern regarding the quality of online education (Hirner & Kochtanek, 2012). Although it is easy to see how formative and interim assessments can be used to measure student understanding in online and blended classes, it is more difficult to see how formative assessments may be employed to directly inform instructional strategies and pacing.

The first electronic solution to formative assessment was the audience response system developed in the early 1970s (Simmons, 1988). William Simmons, an executive at IBM,
reflected on the lack of productivity in corporate meetings. Only one person could talk at a time and each decision required a formal vote. Executives often did not speak their mind because of the desire for conformity with the opinions of their superiors. Simmons worked with Theodore Gordon of the Futures Group to design and develop an electronic audience response system. Simmons applied this technology in corporate meetings and found he got not only greater engagement but also more honest feedback. Simmons found that he could instantly get information on the group’s true consensus (Simmons, 1988).

Today there are many audience response systems, also called “student” or “classroom” response systems, in use in educational settings including dedicated “clickers”, computer software, and smart phone apps that aggregate student inputs (Kay & LeSage, 2009). Such systems track individual responses, display polling results, confirm understanding of key points, and gather data for reporting and analysis. These hand-held dedicated systems allow students to input responses to questions posed by their instructor. The instructor receives immediate statistics on student performance on true-false, multiple-choice and short-answer questions. Studies have shown improved student participation, attendance, and learning with the use of student response systems (Beatty & Gerace, 2009; Bennett & Cunningham, 2009; Buchanan, 2001; Chevalier, 2013; Gok, 2011; Peat & Franklin, 2002). Such systems not only provide information for teachers, they increase accountability for students (Kaleta, 2007). Although student response systems have been shown to be a valuable formative assessment tool, current systems do not provide adequate means for free response questions. They have limited input capabilities and cannot receive complex text, audio, video, or graphic responses that can be used to assess higher levels of understanding. Some uses also require assessments to be prepared in advance, limiting the ability of the teacher to make a spontaneous assessment.

Most student response systems require instructors to create multiple choice and short answer questions prior to class. Although such systems have the advantage of providing detailed and immediate statistics on student understanding, they fail to give any insight into the thinking of the student and the reason for their understanding. To circumvent the limitations of hand-held student response systems, researchers at Colorado School of Mines (CSM) developed free web-based software known as InkSurvey that enables students to use pen-based mobile technologies to respond to the open-format questions of their instructor with diagrams, equations, graphs and proofs (Kowalski, 2013a). The instructor instantly receives student responses and thereby gains real-time insight into student thinking and can immediately reinforce correct understandings and address misconceptions as they develop. InkSurvey has been used successfully in college physics and engineering classes with enrollments exceeding 60 students. Researchers determined that when interactive engineering computer simulations were coupled with real-time formative assessment data collected with InkSurvey, students achieved large and statistically significant learning gains regardless of their learning styles (Kowalski, 2013a).

The formative assessment techniques mentioned so far have been shown to be effective in traditional face-to-face classrooms, but can they be used in synchronous or asynchronous online or blended classes? Indeed, many of the techniques mentioned so
far can be replicated using cloud-based collaborative resources. Reviews of the literature show that interactive online formative assessments can foster a learner-centered focus and enhanced learner engagement (Gikandi, 2011). Online feedback systems that are integrated into the student’s online learning space have been shown to improve student engagement and performance (Chen 2009; Hatziapostolou, 2010; van Gog 2010). Interactive computer-marked assignments and conventional tutor-marked assignments have been shown to help students keep up-to-date in their studies (Jordan, 2009). Others have experimented with social networking to promote peer-to-peer collaboration and formative assessment (Blue & Tirotta, 2011) and some have shown that blogs can be used as a student-based formative assessment tool to cultivate reflective peer-to-peer learning (Olofsson, Lindberg, Hauge & Trond, 2011). Others have shown that anonymous electronic feedback systems can be beneficial in stimulating instructors to make changes to improve the delivery of online courses (Berridge, Penny & Wells, 2012). Collectively, such studies have indicated that web-based formative feedback can be instrumental in improving the student learning experience.

The need for new formative assessment methods
As mentioned previously, schools and universities are encouraged to develop a “culture of assessment” to provide evidence on the effectiveness of instructional programs (Weiner, 2009). Summative assessments provide information after the fact. They tell you what students did or did not master, but they do not provide the information necessary to make changes in instructional or learning strategies while learning is occurring. Although summative assessments may provide powerful incentives for student learning, they do not inform teaching while it is occurring and therefore do not allow instructors and students to alter their approaches to optimize the learning environment. Many teachers agree that formative assessment is very important, but traditional techniques provide incomplete pictures of student understanding. For example, a “show of hands” only tells the instructor the percentage of students who think they understand, and not the percentage that truly understand nor the level of their understanding. Though many of the existing technological solutions work well for pre-planned assessment, they do not fluidly allow instructors to create follow-up prompts in real-time that modify their instruction in response to student needs.

Educators have grappled with this problem for many years and have adopted a variety of techniques in an attempt to perform continuous formative assessments. For example, in the “modeling method” of physics instruction student teams summarize their models and evidence on a small whiteboard that is easily displayed to the entire class. The whiteboard serves as a focus for the team’s report and ensuing class discussions. (Hestenes, 2010; Wells, Hestenes & Swachkhamer, 1995). While this approach has been used effectively it does not produce a lasting record of student’s thinking that can be referred to later. Students’ work disappears as soon as the whiteboard is erased. One solution is to have students put their response on paper to be turned in as in a quick write (Clidas, 2010; Rief, 2002) or in a notebook/journal that students maintain during the course (Roberson, 2010). Both of these produce a lasting record, but the logistical challenges of assessing and maintaining them make it difficult for teachers to use them effectively (Ruiz-Primo, Li, Ayala & Shavelson, 2004).
As we move to blended learning and synchronous online learning, which combines computer-mediated activities with traditional face-to-face classroom methods, we need to think of new ways to use the best of current assessment tools. These environments create a number of new possibilities for formative assessment that allow teachers to quickly see meaningful student responses and adjust teaching based on their needs. There is a need for techniques which provide continuous formative assessment that can be used in traditional, blended and online learning contexts.

**Continuous Formative Assessment (CFA)**

The authors have developed a teaching technique that employs synchronous collaborative web-based documents to perform continuous, real-time formative assessments of students’ understanding so that educators can adjust their instruction to address the immediate needs of their students regardless of whether they are in traditional or online settings. The CFA model has the potential to engage all learners all of the time as they provide feedback, data, quick-writes and analyses in response to instructor prompts. Using this model, teachers have the opportunity to observe all student contributions as they are made.

The CFA model has been made possible by the development of free collaborative web-based spreadsheets, documents, presentations, and drawings (Herr, Foley, Rivas, d’Alessio, Vandergon, Simla, Nguyen-Graff & Postma, 2012a,b; Herr & Rivas, 2010; Herr, Rivas, Foley, Vandergon & Simila, 2011a,b; Rivas & Herr, 2010). Online tools like Google Documents or Windows Office Live allow teachers to develop online documents and share editing privileges with their students. The shared documents provide a platform for formative assessment as both the teacher and the student have immediate access to the documents. For example, in a blended classroom in which students have computers or tablets, or in an online synchronous lesson, teachers can use a shared online spreadsheet to record students responses. Teachers enter student names in column one and pose a question in the header of column two (Figure 1). Students respond to the question in the cell next to their name, providing the teacher with instant information regarding current student understanding of the lesson. This process can be repeated throughout the class allowing teachers to assess their students continuously. The spreadsheet becomes a lasting artifact of student thinking and can be analyzed later or referred to by both the teacher and the students.

Although many companies now offer online documents, Google offers the most comprehensive suite of free resources, and so we shall discuss their offerings in more detail. In 2006 Google acquired Upstartle, the software company which introduced the first web-based word processor. In addition, Google acquired rights to the first web-based spreadsheet from 2Web Technologies (Google Press Center, 2006). In 2007, Google developed the first web-based presentation program (Bodis, 2007) and introduced all three as a free development suite known as Google Drive®. Any individual who opens a free Google account has an automatic link to Google Drive® (formerly called Google Docs®). Users can develop documents, spreadsheets and presentations online using any modern browser, or can import them from a wide range of formats. Google documents are automatically saved to Google servers whose actual location or name is not needed. These documents are described as being located “in the cloud.” As with
related wiki technologies, a revision history is associated with each document so users can review, revise and/or reverse editorial changes.

Cloud-based documents allow for the type of collaboration and sharing environment for productive student learning communities (Falkner & Falkner, 2012). Teachers and students can work on the same file as they co-author reports, creative writing and other document. As students collaborate, each can see which revisions have been made by their colleagues, and can reverse or restore changes by selecting options in the revision history. Rather than working on original files and sending copies for peers to work on, all students work directly on the original so there is no confusion about the current status of the document. Such web-based development resources preclude the need for expensive software, since all one needs is a free downloadable web browser.

Collaborative cloud-based document technology creates new opportunities for formative assessment involving laboratory science experiences. While ideal science laboratory experiences should help develop scientific reasoning and an understanding of the complexity and ambiguity of empirical work (National Research Council, 2006), many laboratory experiences that students receive do not assist in the achievement of these goals. Web-based documents can provide an opportunity for students to understand the complex and collaborative nature of empirical research as they collect and analyze data from multiple lab groups, classes, or schools (Herr et al., 2011a; Herr & Rivas, 2010). Data collection can be simplified by survey tools, such as Google Forms®, that link directly to online Google Spreadsheets®. Teachers or students can develop forms online and then invite students to input their findings. Spreadsheets are created from the data, with records (rows) representing the lab groups, and fields (columns) representing answers to specific questions. Links to survey forms and their associated spreadsheets can be provided by copying document addresses to email messages, blogs, newsgroups or websites. Students reply to the online forms, and together build a single spreadsheet file that is shared by all.

Within moments, an entire class can input their data, generating a table with as many records as there are laboratory groups, and as many fields as there are questions on the form. These data sets can be analyzed with built-in online tools and “mashup gadgets” (web application hybrids), or downloaded to each group for analysis with traditional tools such as Microsoft Excel®. The instructor can easily analyze all contributions on a single screen, regardless of the physical location of the contributors. This provides the opportunity for formative feedback and possibly peer feedback as the results are apparent to all. For example, an online instructor can collect observational weather data from their students and then analyze it in light of weather station reports of temperature, pressure and dew point. As class is conducted in a medium such as Google Hangouts (a free video conferencing) or Collaborate (Blackboard’s tool for synchronous online instruction), both the instructor and all of the students can continuously monitor all student data which is plotted on a Google Spreadsheet. This monitoring allows a new level of formative assessment for data collection, as many errors can be identified and corrected before it’s too late (d’Alessio & Lundquist, in press).
Many classroom experiments call for the measurement or calculation of specific values, such as the density of water, the molar volume of a gas, the wavelength of a laser’s light, or the percentage of root tip cells in mitosis. Students may notice that their values differ from those of other lab teams and thereby gain an understanding of the value of descriptive statistical measures, such as mean and standard deviation, when analyzing experimental data. As students graph class data using web-based spreadsheet tools, they may note bell-shaped distributions and gain a more intuitive understanding of the normal curve and basic descriptive statistics. Bimodal distributions may indicate the use of two different techniques while random distributions may indicate flaws in experimental design or implementation. By analyzing class data sets, students learn the complexity of the natural world and see the need for standardizing procedures and controlling for confounding variables. Thus, collaborative web-based technologies can be employed to provide continuous formative assessment of laboratory techniques (Herr et al., 2010a; Herr et al., 2010b). Many science educators shy away from online and blended learning environments because they believe that such environments do not provide realistic laboratory experiences and lack the community that is so important to scientific research. The CFA model can address many such concerns by bringing students together online to conduct collaborative investigations.

Web-based documents can be employed to help students learn aspects of the nature of science and gain experience working in large teams. Scientists work in research laboratories that are part of larger networks and associations, and share their findings with their peers through journals and conferences. In the traditional college or school science classroom, only the instructor reviews student work. Web-based document technology provides students the opportunity to work cooperatively in the collection of data, analysis and assessment of peer data.

Web-based document technologies (e.g. Google Documents, Spreadsheets, Forms, and Presentations®) provide an environment for collaboration, but online instructors must develop appropriate activities and lessons if they plan to capitalize on the opportunities the technology affords. For example, an investigation may ask students to find the relationship between mass, length, and the period of a pendulum. Students in an online or blended physics class can submit the results from experiments performed at home to a collaborative form or spreadsheet. Relationships that are invisible with the few data points collected by a single lab group become clear with the addition of whole class data. If each group measures the period of a pendulum using different weights and lengths, then students will have large data sets to analyze. Using spreadsheet curve-fitting technology, students can find the equations that best fit the class data. By analyzing whole class data, students can determine that the period of a pendulum is independent of mass, but directly dependent upon the square root of the length of the pendulum. Such conclusions can be made quickly when working with whole class data, but may take a long time if each lab group must independently generate all of the necessary data. Pooled data makes it easier to find mistakes and correct them during the activity. Rather than waiting for the final lab report, teachers and students can assess data as it is input into the cloud-based spreadsheet where mistakes will often show up as outlying points. By performing a formative assessment on student data immediately upon input, the instructor can save students much wasted time trying to interpret flawed data.
Techniques for Continuous Formative Assessment
All of the following techniques use collaborative online resources. In each case, the instructor sets up a document on which students simultaneously enter data, or a folder to which students simultaneously upload documents. The instructor establishes sharing privileges so that students can access these resources using their email login and passwords. By making such resources private, the instructor can identify the contributions made by each student. In addition, the instructor can analyze the revision history to see a chronology of changes made by specific students. The following techniques are possible with both computers and mobile communication devices such as phones and tablets.

CFA Technique 1- Online Quick-write - The electronic quick-write is perhaps the most useful of all of the CFA techniques. The instructor sets up a spreadsheet such that student initials, names or ID numbers are in column 1. He or she then starts asking questions and provides a brief title at the top of the adjacent column. The instructor can tell when students start to type because their cells turn gray. Once they press the enter key, their entry appears in the appropriate column. Figure 1 shows the first few rows and columns of a quick-write that was made for a particular class. The first column shows that all but one of the students (row 14) know the mathematical definition of pressure. The instructor then asked the students to complete the sentence, pressure is… In this open ended environment, students produced a variety of responses (column C) which indicated that they did not truly understand the formula which they had just accurately written.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>initials</td>
<td>Pressure equation</td>
<td>Pressure is...</td>
<td>predictions of the candle / flask</td>
<td>how do you collapse a tank car?</td>
</tr>
<tr>
<td>2</td>
<td>CV</td>
<td>P=ff/A</td>
<td>force</td>
<td>the flame will go out</td>
<td>heat water inside, let it evaporate, then seal off tank</td>
</tr>
<tr>
<td>3</td>
<td>DF</td>
<td>f/a</td>
<td>weight weighing down on you</td>
<td>flame will go out</td>
<td>heat water inside</td>
</tr>
<tr>
<td>4</td>
<td>SA</td>
<td>p=f/a</td>
<td>gravity</td>
<td>water turn to vapor, then flame go out if available oxygen is burned/used up</td>
<td>water inside and heated tank with cold surroundings</td>
</tr>
<tr>
<td>5</td>
<td>GG</td>
<td>p=f/a</td>
<td>force over a specific area</td>
<td>some liquid will rise and candle will go out</td>
<td>lower pressure inside, heat water inside and let it evaporate into vapor, seal</td>
</tr>
<tr>
<td>6</td>
<td>HE</td>
<td>P=force of a unit volume</td>
<td>force</td>
<td>flame will go out, water level will increase on the outside, level on inside will be less</td>
<td>change in temperature closed to open container</td>
</tr>
<tr>
<td>7</td>
<td>NG</td>
<td>P = f/A</td>
<td>force pushed onto lower pressure to raise to high pressure</td>
<td>pressure inside drops as steam condenses - Outside pressure pushes water up</td>
<td>Have water inside tank, heat, seal the hose attached to tank with cooler temperature water</td>
</tr>
<tr>
<td>8</td>
<td>HH</td>
<td>p=f/a</td>
<td>pressure is a force</td>
<td>the water is going to go up a little into the flask and form the flame out</td>
<td>heat up water inside and then seal the tank</td>
</tr>
<tr>
<td>9</td>
<td>JK</td>
<td>p=f/a</td>
<td>the force on an object</td>
<td>candle will create steam, the water will rise and put out the candle</td>
<td>heated water inside of the tank, then sealed and cooled the tank</td>
</tr>
<tr>
<td>10</td>
<td>LO</td>
<td>p=f/a</td>
<td>ratio of force distribution</td>
<td>the water will rise and put out the fire</td>
<td>put water inside and then heat it up and seal it</td>
</tr>
<tr>
<td>11</td>
<td>TY</td>
<td>force on a given area</td>
<td>force on a given area</td>
<td>candle flame goes out, gas pushes water level up</td>
<td>heated water in open tank then seal</td>
</tr>
<tr>
<td>12</td>
<td>SS</td>
<td>force per area</td>
<td>a force</td>
<td>the water level should rise in the flask.</td>
<td>same way as the can</td>
</tr>
<tr>
<td>13</td>
<td>SR</td>
<td>p=f/a</td>
<td>force on something</td>
<td>candle will go out</td>
<td>lower pressure inside the tank, higher pressure outside</td>
</tr>
<tr>
<td>14</td>
<td>FR</td>
<td>P=f</td>
<td>pressure is a force</td>
<td>The heat from the candle will make it buoyant/ flame goes out</td>
<td>evaporate a small am of water then seal the tank</td>
</tr>
<tr>
<td>15</td>
<td>DW</td>
<td>P=f/A</td>
<td>force per unit area</td>
<td>Flask will get smoky, then flame will go out, then water will rise</td>
<td>Fill with steam, seal and wait</td>
</tr>
</tbody>
</table>

Figure 1. Example of an electronic quick-write in which a teacher asks students to respond to prompts which are typed in the top row of a spreadsheet. Each student uses the row with their initials.

By examining the data in columns B and C, the instructor is able to do a quick formative assessment regarding students’ understanding of pressure. Namely, students seem to
“know” the formula for pressure, but do not know how to express the formula in words. Being able to ask open-ended questions enables more complex questions requiring students to demonstrate understanding. This provides a “moment of contingency” at which the instructor needs to illustrate how to turn algebraic equations into sentences and thus help students understand the meaning of this and future equations. Without this formative assessment tool, it is quite possible that the instructor could continue teaching, assuming that students truly understood the concept of pressure.

In column D students are asked to make a prediction regarding what will happen when a flask is inverted on top of a burning candle that is standing in a tray of water. This question was asked as a follow-up to a similar activity where students observed soda cans spontaneously collapsing under atmospheric pressure when steam inside the empty cans condensed. A quick survey of column D shows the instructor that only one student (row 7) seems to make the connection between the two phenomena. The instructor is then prompted to show a video of a railroad tank car that collapses under normal atmospheric pressure. In column E we see that nearly everyone is making a correct prediction, which is most simply described in row 15. Finally, the instructor assesses his or her students’ knowledge of atmospheric pressure by asking a question in which they must determine the height to which air pressure can push a column of water in an evacuated tube. At this point, the instructor sees only two errors (rows 7 and 10) and decides that it is appropriate to move to the next level of understanding regarding pressure.

With CFA, instructors open a single spreadsheet document and simply add multiple worksheets to it. If each worksheet is dated, the instructor has a comprehensive picture of student understanding for each day of instruction. Eventually students stop raising their hands to answer questions, and automatically enter their responses in the spreadsheet. The instructor can quickly scan the spreadsheet for blanks. Any blank indicates that the student was either off task or unable to answer the prompt. In a normal classroom, students often defer to the “good students” who offer verbal responses. The instructor gets only one data point to go on, and it is generally data from one of the best students in the class who is willing to raise his or her hand in order to contribute.

The online quick-write provides instructors the opportunity to get student responses on many questions in a single period. This technique works very well in online environments and provides the instructor with immediate data regarding the engagement and understanding of all participants, regardless of their physical location.

CFA Technique 2 – Collaborative Presentation – Instructors can assess student understanding by assigning each an individual page in an online presentation and watching the presentation develop in response to a teacher prompt. Figure 2 shows a presentation that was made when trying to illustrate the concept of order of magnitude in measurements. Students were assigned an order of magnitude and were to find a photo of an object at that scale. The collaborative presentation differs from the collaborative spreadsheet in that each student is assigned a unique page rather than a unique row in a spreadsheet. These pages can accommodate not only text responses, but also audio and video files.
Figure 2. Slides from a collaborative presentation. Each student added one slide to illustrate an order of magnitude of size.

CFA Technique 3 – Collaborative Diagram Album – Teachers often ask students to diagram the subjects being discussed in class. The whiteboard methods used by Hestenes (2010) and others provide a way of quickly sharing student-generated diagrams. To see students work in an online or blended setting, the teacher can ask students to use smart phones to scan their drawings and upload them to the class folder in the cloud. In Figure 3, students were asked to draw an apparatus for measuring the wavelength of a laser beam. After each student completed their drawing on paper, they scanned it and entered it into the shared folder. When the instructor clicks on the folder, he or she can review the contributions of all students simultaneously, and can bring student work up for illustration. With collaborative albums, teachers can monitor the thought processes of their students in real time. Unlike the whiteboard approach, the students’ work is not erased when the next question is asked and can be used when students are spread around the world.
CFA Technique 4 – Collaborative Photo/Movie Album – As previously demonstrated, the CFA model can use any type of media, at any time, from any part of the world. In technique 3, the instructor set up a collaborative album into which students deposited scans of diagrams made with pencil or pen and paper. Sometimes, photographs or movies are more telling than diagrams or text. Using technique 4, students can take photographs or movies on their smart phone and send them to a shared folder. For example, figure 4 shows the movies made by students trying to illustrate the motions shown by the graphs. Some students made movies using their fingers, while others using the mouse, a toy car, or their entire body. Once the movies are collected, the instructor plays them back to the students in his or her online class and they evaluate their accuracy using an online quick-write. In addition to harvesting movie data, the instructor can also get photographs from his or her students. Figure 5 illustrates a shared album into which students deposited a variety of photographs of science-related topics they had seen in their communities or travels. A quick glance at the thumbnails in the album allows the online instructor to do a formative assessment on their success in meeting this requirement.
Students create movies illustrating motion and submit them to a collaborative folder in the cloud.

Figure 4. Collaborative movie album. Movies submitted by students to illustrate movements corresponding to graphs.
CFA technique 5 – Collaborative Data Plotting – One of the challenges of online learning is that it is difficult to learn from one’s peers. You can’t just look over their shoulder while they are doing an activity or experiment to get ideas, nor can you hang around after class to discuss techniques and strategies. Fortunately, cloud-based collaborative documents allow you to meet with your peers in cyberspace. Figure 6 shows the data collected by numerous students in a physical science class. Students were tasked with the goal of determining the factors that cause something to sink or float in water. Students assemble block combinations that vary in volume and mass and then determine if they sink or float in water. The instructor has prepared an online spreadsheet with cells for each lab group. As they enter the mass and volume of floaters or sinkers, marks are plotted on the graph. The graph develops a clear pattern when the data points of each individual or lab group are reported. Eventually, students see a clear line between sinkers and floaters and infer that anything above this line will sink in water, and anything below this line will float in water. As is intended they deduce that the mass to volume ratio of the blocks determines whether they float or sink, and the dividing line between the two objects represents the mass to volume ratio of the fluid in which they are placed. Thus, students discover the concept of density by discovery rather than by direct instruction. As students see their data plotted, they may also see some outliers and come to question the quality of such data. Outliers generally indicate something important or simply bad data. In this case, the student reversed the mass and volume measurements, and once they saw their error, they quickly corrected it. Thus, students can perform formative assessments on the evaluate quality of their own data and draw conclusions based upon their own data as well as the data of their peers.
Figure 6. Collaborative Spreadsheet – Students submit their data to online spreadsheet an make interpretations based on pooled data.

Research Questions
The CFA model presented in this chapter raises a variety of interesting questions related to the effectiveness of formative assessment in online and blended learning environments.

(1) Instructor Formative Assessment - To what degree do instructors adjust their instruction to meet student needs when employing CFA compared to traditional models of instruction?

(2) Student Formative Assessment - What effect does the CFA model have in motivating students to apply formative self-assessments such as self-monitoring and self-correcting?

(3) Accountability / Engagement – To what degree are students engaged in the instructional process by the use of CFA compared to traditional models of instruction?

(4) Student Learning - What effect does the CFA model have on student learning?

Methodology/Approach
To address these research questions, researchers are performing mixed-methods studies using survey instruments, observations from third-party researchers, and interviews with teachers and students. A preliminary survey was delivered online in computer equipped classrooms at the end of the Fall Semester of 2012. The participants were students in three courses at California State University, Northridge, in which CFA was employed on a daily basis throughout the semester. Most survey questions were given in the Likert scale format. Seven of the nearly 100 questions in the survey were free response. The questions asked students to compare the effectiveness of the CFA pedagogy with other methods that they had received at the university with respect to accountability, engagement, metacognition, social learning, and intent to employ similar techniques in
their own instruction. Fifty-one of seventy students completed the voluntary survey that included additional questions related to program evaluation (response rate = 73%). The students were graduates of one of the following three courses: Website Development for Teaching Science (a masters degree course for in-service science teachers), Methods of Teaching Science (a credential course for pre-service science teachers), and Computers in Instruction (a credential course for secondary school teachers, regardless of field). Twenty-one respondents were in-service teachers enrolled in a masters degree program in secondary science education, and thirty were pre-service secondary school credential students representing a variety of disciplines. Fifteen of the respondents were male, and thirty-six were female. Ethnicity demographics of the participants were not recorded in the survey.

We are currently engaged in additional research efforts to clarify the effectiveness of the CFA pedagogy in promoting effective formative assessment. Independent researchers are making observations, conducting surveys, and interviewing professors, teachers and students in university and secondary school courses in which CFA is employed.

**Results/Findings**

A variety of studies are currently in process to address the research questions we have proposed. We shall discuss preliminary findings, but look forward to the results of the ongoing research to provide more comprehensive answers. Students were asked to compare how accountable they felt to their instructor during instruction. They were asked to compare the course they had taken in which CFA was employed with all other courses they had taken at the university. For example, in the first question (Figure 7), students were asked to evaluate how accountable they felt to their instructor during instruction by responding to a five-point scale with values ranging from “much less accountable” to “much more accountable” compared to all other university classes they had taken. The top two values were combined to indicate respondents’ general response. Figures 7 and 8 show the results of the survey. Participants reported substantial benefits of the CFA model for the dimensions identified in our research questions:

(1) **Instructor Formative Assessment** -- Six professors at California State University Northridge (representing the departments of chemistry, geology, biology, and secondary education) have employed the CFA technique. Personal discussions with these professors indicate that all believe that CFA provides them with valuable information regarding the level of student understanding, allowing them to modify lessons to maximize student engagement and learning.

(2) **Student Formative Assessment** – Seventy-four percent of respondents said that they were more mentally engaged in the instructional process as a result of the CFA approach, and 85% said that they were more likely to catch their own errors. These early results suggest that, in a class employing CFA techniques, students display an increased propensity to self-monitor and self-correct and are subsequently taking more responsibility for their own learning during instruction.

(3) **Accountability / Engagement**– The initial study showed that 77% of respondents felt more accountable to the instructor, 71% felt more accountable to peers, 75% felt more accountable for their own learning and 74% felt that they were more mentally engaged as a result of the CFA approach.
(4) Student Learning - Eighty-nine percent of respondents thought that more learning would occur if they used CFA in their own secondary school classrooms, and 96% said they intend to use the CFA model in their own instruction. This self-reported data is supported by research from colleagues at the Colorado School of Mines working with a CFA tool known as *InkSurvey* (as described above).

Figure 7. Survey of participants’ perspectives of the effectiveness of CFA with respect to accountability and engagement in comparison with all other university courses in which CFA is not used.
Discussion & Implications

The continuous formative assessment (CFA) model is well-suited for online and blended learning environments. Online learning has always been suspect because instructors have been unable to measure the level of student engagement nor verify that the individual answering summative assessments is the individual enrolled in the class. The CFA model has been shown to enhance accountability, providing a window into student engagement, and a profile of student thinking during synchronous online or in-person instruction.
The CFA model helps establish an environment that more closely resembles the professional learning environment in which colleagues share their ideas with each other and provide feedback and critique. An instructor can elect to make some or all of student contributions visible to the entire class. In such an environment, students can evaluate their ideas and contributions in light of those of their peers, just the way professionals share their findings and provide critiques of their colleagues’ work.

Preliminary data from pre-service teachers indicates tremendous enthusiasm for the CFA model, and dramatic improvements in collaborative online technologies suggest that these strategies will continue to grow in popularity. The move away from traditional print resources towards computer-based learning suggests an increasing familiarity with the technologies that support CFA. For example, South Korea announced that it intends to replace textbooks with tablets by 2015 (Kim & Jung, 2010). This trend is expected to grow worldwide, and with it will come increased understanding of and access to the technologies necessary for CFA.

**Conclusions, Recommendations, and Future Research**

The CFA model provides a mechanism by which instructors of online and blended courses can assess the learning of their students during synchronous instruction. As instructors analyze student data, they have an opportunity to adjust their instruction to immediately meet student needs. As a result of increased accountability and engagement, it is anticipated that students will perform better and be less likely to fall behind or drop out of online and blended courses. Although there are a variety of research initiatives underway at the university where this pedagogy was developed, it is clear that more research needs to be done in other institutions and settings.
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Appendix F: Paper Presented at Association of Science Teacher Educators (ASTE)

Title: Computer Supported Collaborative Science (CSCS): An Instructional Model for Teaching the NGSS

Program Abstract

Computer Supported Collaborative Science (CSCS) is a 4 year effort to train science teachers to use online collaboration tools (e.g. Google Docs) with their students to support science inquiry. We discuss our professional development methods and the impact on teacher practice and student learning the need for collaboration described in the NGSS.

Proceedings Abstract

Computer Supported Collaborative Science (CSCS) is an ongoing research project designed to train science teachers in how to use online collaboration tools with their students. For the past four years, faculty from the Colleges of Education and Science and Math at Cal State Northridge (CSUN) have worked with pre-service and in-service science teachers on how to use tools such as Google Docs to enable students to share data and ideas online. As more and more schools invest in technology for classroom use, teachers need to learn how to take advantage of these tools. Instead of using technology to have students watch videos or read websites, CSCS teaching methods engage students in hands-on science, pooling data, analysis and interpretation. CSCS provides teachers with techniques to help meet the demands of the Next Generation Science Standards (NGSS) through the use of collaborative inquiry and formative assessment. Online tools support English Language learners and promote science literacy skills by engaging students in writing and giving feedback to their peers.

This paper set will discuss the CSCS pedagogy and teacher professional development methods and subsequent science teaching practices as seen in the findings from the project so far. We present four papers discussing: (a) CSCS pedagogy designed to address the NGSS, (b) how collaboration and data pooling promote student’s metacognition, (c) the evolution of the preservice science methods course and (d) the use of clinical teaching experiences for professional development method to help teachers learn both the technology and pedagogy of CSCS. These papers stem from our
experiences teachers in the urban schools of North Los Angeles including dozens of pre-service teachers and over 70 in-service science teachers who have participated in CSCS summer workshops. We have collected data on their participation in the workshop as well as their teaching practice back in the classroom. The analysis of this data has led us to explore new professional development methods from clinical teaching to MOOCs.

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**Proposal**

Both the Common Core State Standards (CCSS) and the Next Generation Science Standards (NGSS) place substantially more emphasis on science process skills and scientific explanations than exist in the current state standards. Many teachers are not yet ready for this shift. Less experienced teachers tend to rely on didactic techniques such as reading textbooks rather than experiential learning or inquiry instruction that promote higher order thinking skills (e.g., Newton, 2002). Both in-service and pre-service teachers will need to develop new teaching skills to meet the demands of NGSS. At the same time, technology is slowly becoming available in classrooms but instruction lags even this slow adoption. We surveyed local teachers and found almost a third (31%) have reliable access to computers for the students. But of those teachers, less than half (44%) actually use the computers at least once a week. Instead we hear of laptops collecting dust in closets. Technology can support the changes in teaching that we need, but teachers need support to make this a reality in the classroom.

Computer Supported Collaborative Science (CSCS) is an ongoing research project to train science teachers in how to use online collaboration tools with their students to support inquiry and meet the demands of the NGSS. For the past four years faculty from the California State University Northridge (CSUN) College of Education and College of Math and Science have collaborated on an effort to improve science instruction through the use of online collaboration tools such as Google Docs in science classrooms. Collaboration tools enable students to share data and ideas online and get feedback on their thinking (Herr & Rivas, 2009). As more and more schools invest in technology for classroom use, teachers need to learn how to take advantage of these tools. Instead of using technology to have students watch videos or read websites, CSCS teaching methods engage students in hands-on science, pooling data, analysis and interpretation. CSCS provides teachers with techniques for formative assessment in the classroom and give students a better understanding of scientific research and how scientists collaborate and share results. Online tools also support English Language learners and science literacy skills by engaging students in writing and giving feedback to their peers.
This paper set will discuss the CSCS pedagogy and teacher professional development methods and subsequent science teaching practices as seen in the findings from the project so far. We present four papers discussing: (a) CSCS pedagogy designed to address the NGSS, (b) how collaboration and data pooling promote student’s metacognition, (c) the evolution of the preservice science methods course and (d) the use of clinical teaching experiences for professional development method to help teachers learn both the technology and pedagogy of CSCS. These papers are born of our experiences with science teachers in the urban schools of North Los Angeles. Our pre-service science teacher preparation has adopted this approach and produced dozens of young teachers ready to utilize CSCS in the classroom. Additionally over seventy in-service science teachers have participated in CSCS summer workshops over the past four years. We have collected data on their participation in the workshop as well as their teaching practice back in the classroom. The analysis of this data has led us to explore new professional development methods including clinical teaching.

The Pedagogy of Collaboration: NGSS and the Connected Classroom

*Brian Foley & John M. Reveles*

The Next Generation Science Standards (NGSS) provide an opportunity to make significant changes in how we teach science including bringing instructional methods into the 21st Century. Computer Supported Collaborative Science (CSCS) is an instructional model that utilizes a collection of technology teaching tools that directly address these NGSS goals. This paper provides the conceptual basis for the pedagogical approach underlying CSCS and discusses the ways that this instructional model directly addresses the NGSS in the classroom. The core idea of CSCS is to utilize the connectivity of the internet to enable students to share information and collaborate with students in their classroom and beyond. Collaborative documents like Google Spreadsheet allow students to simultaneously answer questions and give ideas creating new forms of collaboration. We utilize these tools to create a student-centered science class that engages students in inquiry and the eight Science & Engineering Practices identified by the NGSS. We use the practices as a structure for describing the pedagogy of collaboration.

1. **Asking questions (for science) and defining problems (for engineering)**
   Collaborative documents allow students to submit ideas questions to the group to get feedback and to allow the group to reach consensus on research procedures.

2. **Developing and using models**
Online documents allow students to articulate models via writing, drawing and diagraming. Because documents are stored in the cloud, students can link models to the data collected from experiments to see how well their models match.

3. Planning and carrying out investigations
Like questions, research procedures can be constructed collaboratively, allowing the teacher to engage students in designing research while still ensuring they develop effective plans. Data can be entered online and pooled with other students to create more powerful data sets and allow students to compare data with others (see d’Alessio, Lundquist & Reveles ibid).

4. Analyzing and interpreting data
Data entered online can be easily shared or pooled with other students and the teacher to help scaffold the analysis.

5. Using mathematics and computational thinking
Spreadsheets with graphs or scatter plots allow students to explore data in different ways and create images to illustrate their findings.

6. Constructing explanations (for science) and designing solutions (for engineering)
Results bring together data and analysis (including visualizations) and are easily shared and compared to help the class reach consensus.

7. Engaging in argument from evidence

8. Obtaining, evaluating, and communicating information

Ways that CSCS Engages Students in NGSS Practices
The CSCS model provides a pedagogical approach that draws upon collaborative teaching tools for engaging students in the scientific and engineering practices that are linked to the NGSS by facilitating student development of such practices. For example—using CSCS pedagogy—a teacher can solicit research questions surrounding a particular scientific phenomenon being investigated. Students then enter their own research questions into a blog and simultaneously see the ideas of their classmates. Afterwards, the teacher highlights specific questions and illustrates how they may be refined into researchable questions. Next, students are required to post suggestions for their peers. Throughout this iterative process, students learn to ask scientifically researchable questions by seeing numerous examples edited and refined in the collaborative environment of the blog. In this way, CSCS supports students developing metacognitive skills by utilizing near-instantaneous peer feedback during every part of the inquiry process. Moreover, CSCS pedagogy provides tools for teachers to assess student thinking to identify misconceptions and check understanding. It does so by providing immediate identification of student misconceptions by pooling whole-group data sets into a classroom corpus of data. Thus, students are able to see where they might be off the mark in their analysis during the actual investigative process itself instead of after the fact. This type of immediate misconception identification “in vivo” allows for real-time
If science teachers at all levels are going to be expected to engage their students in the Next Generation Science Standards (NGSS), it then becomes necessary to provide them with the tools needed to facilitate the engagement of authentic science learning. CSCS provides a pedagogical model that does so by creating a culture of collaboration in today’s connected classrooms.

A Case Study of how CSCS has Transformed Instructional Practices
Norman Herr and Marty Tippens
This paper presents a case study analysis regarding the evolution of teaching practices of two instructors (professors at California State University, Northridge and Woodbury University). Each of these instructors has gradually adopted a teaching approach that utilizes the principles of Computer Supported Collaborative Science (CSCS) in order to deliver science and math content to their students.

The investigation uses a case study approach to document the changing practices as they have occurred over time from a teaching pedagogy dominated by lecture-based instruction to a collaborative whole-class approach that engages all learners in the collection, analysis, and interpretation of individual data in the context of whole-class data. Class sessions have been recorded using Elluminate/Collaborate, and student contributions have been recorded using collaborative online documents. An analysis of these artifacts indicates an increasing involvement of students in asking questions and defining problems. In addition, the professors spend significantly more time guiding students in the analysis and interpretation of data and encouraging them to construct explanations from evidence. Records indicate a significant change in teaching style, away from pre-digested explanations towards argument from evidence. This study documents how classroom activities model the science and engineering practices specified in Dimension-1 of the Next Generation Science Standards (NGSS).

Using Computer Supported Collaborative Science CSCS: The Impact on Teacher Practice and Student Metacognition
Matthew A. d’Alessio, Loraine Lundquist, and John M. Reveles
This paper presents a theoretical perspective on the impact of a Computer Supported Collaborative Science (CSCS) teaching methodology on teachers’ teaching practices and students’ metacognitive functioning. We focus our theoretical argument on the notion that the use of a CSCS teaching method provides teachers with the opportunity to change their current science teaching practices to engage students in 21st century skills by using collaborative tools to promote student metacognition. The paper provides a conceptual basis for understanding how CSCS is utilized by drawing on data collected during university course instruction. Our theoretical supposition uses data excerpts—drawn from university instruction—showing how the public comparison of student artifacts (ideas or data) provides a forum that encourages metacognition. Specifically, these data support our theoretical position by exemplifying two related ways that CSCS supports student metacognition. First, utilizing a CSCS teaching approach supports student metacognition by allowing students to see the difference between their own scientific thinking (individually) and the thinking of the rest of their collaborators (collective). Second, using a CSCS teaching approach supports student metacognition during science investigations by allowing students to identify patterns and outliers in data in real-time instead of after the fact.

**Seeing the Difference Between Individual and Collective Cognition**

Research about the differences between novice and expert thinking in a given field indicates that experts constantly monitor and evaluate their progress, a category of metacognition. Experts maintain a vast library of background knowledge and cognitive models that they use as a basis for comparison for new information, but novices lack this library. Without such a basis for comparison, novices are less able to engage in meaningful "self-checking." While it is not possible to instantly impart an expert's vast background knowledge on a novice, CSCS methods of instruction provide a comparison by making an entire classroom's ideas public. A student can therefore see his or her ideas beside the ideas of peers and the comparison automatically prompts students to self-check. Unlike revealing a correct answer after students submit responses (allowing the student to passively accept the correct response without evaluation), students must contemplate which elements of their classmates' answers are valuable.

**Identifying Real-Time Patterns and Outliers**

The theoretical position taken in this paper posits the notion that using a CSCS teaching approach can help science teachers support student metacognition during science investigations by allowing students to identify patterns and outliers in data in real-time. Many novice students have no experience at distinguishing high quality, precise data from inaccurate, “bad” data. Researchers in geoscience education have shown that training novices to recognize complex patterns in visual data (such as quantitative graphs) works best when students are simultaneously shown an example of the pattern and a
related counter-example that does not match the pattern (Ormand et al., 2009). The comparison calibrates the novice into all the nuances of the pattern. CSCS accomplishes this goal by showing students their own (individual) data in the context of everybody else’s (collective) data in the class. Outliers with errors in data or calculation are much easier to spot when seen in comparison with collective data ranging from low level poor quality data or calculations high quality data and/or calculations. Repeated exposure to this process over time (e.g., during several weeks, over the course of a semester, or across an entire school year) helps students develop the internal mental models needed to ask and answer the fundamental question, "Do these data look reasonable?" We provide examples from our classrooms showing how students spontaneously self-monitor their data, notice errors, and fix them when they see their data beside other students' data.

Our thesis in this paper is that the Computer Supported Collaborative Science (CSCS) teaching method provides teachers with 21st century teaching tools necessary to engage students in individual and collective metacognitive thinking.

**Clinical Teaching as In-Service Professional Development for CSCS**

*Kelly Castillo & Virginia O Vandergon*

This study follows a cohort of in-service secondary science teachers as they participate in a summer professional development program based on the Responsive Teaching Cycle (RTC) intended to promote the use of Computer Supported Collaborative Science (CSCS). As opposed to traditional professional development, which is typically delivered in the form of a workshop, the RTC model consists of clinical teaching followed by collaborative daily reflection (Cheng, 2010). Clinical teaching, a model typically utilized during the student teaching experience, also has implications as a professional development tool for in-service teachers. When introducing a specific pedagogy, clinical teaching provides teachers with the structured hands-on experience, as well as the support and guidance to practice implementation before bringing the pedagogy back to their school year classrooms (Grossman, 2010). Additionally, the collaborative planning time built into the model allows teachers to develop and foster Professional Learning Communities (PLCs), support structures intended to further aid participants in implementation (Musanti & Pence, 2010; Richmond & Manokore, 2011).

Preliminary findings from the first year of implementation suggest that the RTC model leads to increased teacher confidence when implementing CSCS in the summer classes as well as a greater understanding of the pedagogical benefits of the CSCS model (Foley, Castillo, & Kelly, 2013). Additionally, teachers report that the RTC model has been helpful in assisting in their understanding of the various CSCS tools. Following the first summer, almost all (7/8) teachers reported that they were “Highly Satisfied” with the
collaborative planning aspect of program and all teachers were either “Confident” or “Highly Confident” that they would be able to successfully implement CSCS during the coming school year. Continued research will investigate the impact of this form of professional development, now in its second year, on both new and returning teachers as well as investigate the impact of the program on school year implementation of CSCS.

Conclusion
We see this as a time of dramatic changes in science education. Not only new standards, but new tools as well. The Los Angeles Unified School District just announced plans to provide tablets to all students in the district - in part to meet the needs of Common Core assessments. Other districts will likely follow suit. These changes provide an opportunity to shift the way science is taught. The findings from the CSCS project show how to combine technology and pedagogy to help teachers meet the challenges of the new era. Science teacher educators can learn about the challenges of this approach and how we have adapted to meet them. At previous ASTE meetings we have conducted workshops on CSCS techniques. This paper set provides a chance to describe the methodology and findings in more detail.

References


Appendix G: Paper presented at E-Learn


Using Scanning Apps on Smart Phones to Perform Continuous Formative Assessments of Student Problem-Solving Skills During Instruction in Mathematics and Science Classes

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Abstract - Mathematics and science teachers can now collect samples of student diagrams and multi-step solutions in real-time to make formative assessments of student skills. Students draw their diagrams or perform their solutions on paper, and then scan them with CamScanner® or a similar cell phone app equipped with direct-upload to DropBox® or similar cloud-based file-synchronization system. The instructor creates a shared folder for each class, and subfolders for each question or problem. Students upload scans of their work to the appropriate folder. Within a few moments, the instructor sees everyone’s diagrams and problem solutions in a single window and ascertains the level of student understanding so that instruction can be adjusted appropriately to meet real-time needs. In the process, instructors obtain a permanent cloud-based digital record of all student work, allowing them to track student progress over time.

Need for Formative Assessment

Schools and universities have been encouraged to develop a “culture of assessment” to provide evidence on the effectiveness of instructional programs (Weiner, 2009). Although the emphasis on assessment has produced a wealth of literature, legislation, initiatives, reforms, and professional development, the vast majority has focused on assessment of learning (summative assessment) rather than assessment for learning (formative assessment). Formative assessment is generally defined as a process used by teachers that provides feedback by which they can adjust ongoing teaching and learning to improve achievement during the process of instruction (Popham, 2008). What
makes formative assessment ‘formative’ is that it is immediately used to make adjustments to instruction to meet the needs of the learners during the construction of understanding (Shepard, 2005).

Limitations of Classroom Response System’s & Dedicated Apps

There are numerous Classroom Response Systems (CRS) such as Turning Technologies®, iClicker®, Audience Response Systems® and mobile apps including Socrative®, Poll Everywhere®, TopHat Monocle®, ClickerSchool®, Text the Mob®, Shakespeak®, Naiku Quick Question®, Edmodo®, that can be used to collect information from students for the purpose of formative assessment. Such systems may track individual responses, display results from polls, confirm understanding of key points, and gather data for reporting and analysis. These hand-held dedicated systems allow students to input responses to questions posed by their instructor. The instructor receives immediate statistics on student performance on true-false, multiple-choice and short-answer questions. Studies have shown improved student participation, attendance, and engagement with the use of CRS’s (Beatty & Gerace, 2009; Bennett & Cunningham, 2009; Buchanan, 2001; Chevalier, 2013; Gok, 2011; Peat & Franklin, 2002). Such systems not only provide information for teachers, as effective tools in formative assessment, they increase student’s accountability for their own learning (Han & Finkelstein, 2013; Akpanudo, Sutherlin, & Sutherlin, 2013; Black & Wiliam, 2009; Kaleta, 2007). Although CRS’s have been shown to be a valuable formative assessment tool, current systems do not provide adequate means for free response questions. They have limited input capabilities often allowing a maximum of five response choices and cannot receive audio, video, or graphic responses necessary to assess higher levels of understanding (Price, 2012).

Most CRS’s require instructors to create multiple choice and short answer questions prior to instruction. As a result, lessons may tend to be scripted and rigid as teachers adjust their instruction to include pre-written questions. CRS’s also require a significant institutional commitment. Such accountabilities include the determination of a common CRS platform on which all departments agree and whether the cost of individual CRS devices will be the student’s responsibility or that of the school (Chan, Li, & Tam, 2011). In a recent study identifying ten factors that cause resistance in use of CRS’s among secondary school STEM teachers, timely development of questions was given as one of the two most significant issues (Beatty, Feldman & Lee, 2011).

The authors consider that a more ideal platform would allow teachers to generate questions “on-the-fly” as they naturally develop in the course of classroom discussion. Each classroom of students is unique, and teachers need formative assessment tools that provide flexibility to ask “spur-of-the-moment” questions of any nature. For example, a teacher may suspect that students are confused about the causes for seasonality. He or she may then ask them to draw a diagram that shows why Earth experiences changing seasons. By analyzing diagrams from the entire class, the teacher may discover a variety of misconceptions and then adjust their instruction to resolve these misconceptions and insure deeper understanding. Unfortunately, such data cannot be collected by dedicated CRS’s nor polling/questioning apps. (Herr, N., Rivas, M., Tippens, M., Vandergon, V., d'Alessio, M., & Nguyen-Graff, D., 2013).
To circumvent the limitations of hand-held CRS’s and mobile apps, colleagues at Colorado School of Mines (CSM) developed free web-based software known as *InkSurvey* that enables students to use pen-based mobile technologies to respond to the open-format questions of their instructor with diagrams, equations, graphs and proofs (Kowalski, 2013). The instructor instantly receives student responses and thereby gains real-time insight into student thinking and can immediately reinforce correct understandings and address misconceptions as they develop. *InkSurvey* has been used successfully in college physics and engineering classes with enrollments exceeding 60 students. Researchers determined that when interactive engineering computer simulations were coupled with real-time formative assessment data collected with *InkSurvey*, students achieved large and statistically significant learning gains regardless of their learning styles (Kowalski, 2013).

Although *InkSurvey* is an excellent tool for continuous formative assessment, it requires that students enter their responses directly on devices equipped with touchscreens. There are two issues with this requirement. Firstly, departments will find that the *Ink Survey* is similar to the CRS’s in that it also requires institutional commitment in the form of agreement on device platform and professional training. Secondly, many students find it difficult to draw complex diagrams or write detailed solutions on touch screens because they lack the precision that one is accustomed to when writing on paper. We suggest that instructors not abandon paper when performing formative assessments. Rather, we suggest that teachers ask students to draw diagrams and perform complex solutions on paper. Students’ are then directed to upload their solutions to a cloud-based folder that the instructor can monitor.

Fortunately, it is now possible for students to scan work that they have done on paper and submit it to a cloud-based file system. Students draw their diagrams or perform their solutions on paper, and then scan them with CamScanner® or a similar cell phone app equipped with direct-upload to DropBox® or similar cloud-based file-synchronization system. The instructor creates a shared folder for each class, and subfolders for each question or problem. Students scan their work and upload it to the appropriate folder. This technique affords instructors the opportunity to view the whole of student responses in a variety of useful ways. For example, the scanned work can be arranged as a matrix and projected to the class for review and discussion of the students’ levels of understanding. Alternatively, the instructor can view the work privately and select best examples for projection to the class. Following this review and discussion, the instruction can then be adjusted appropriately to meet real-time needs. In the process, instructors obtain a permanent cloud-based digital record of all student work, allowing them to track student progress over time. This provides an additional level of assessment between pre and post-tests (Price, 2012). This session will introduce participants to this innovative and efficient method of collecting real-time artifacts of student problem-solving skills in both face-to-face and online mathematics and science classrooms.

**Examples from Mathematics Classrooms**

The smart-phone scanning and displaying process has been particularly effective in revealing and addressing the breadth of misconceptions students hold with respect to a variety of mathematical concepts. Traditional formative assessment methods, such as the art of questioning, the exit survey, and the evaluation of class-work and homework also
reveal such misunderstandings. However, the traditional methods lack the immediacy in enlightening the teacher of learning errors. Finding and addressing these problems in real-time is a significant feature of the *scan and post* process. It allows the teacher to adjust the lesson to focus on specific areas of need. In addition, *scan and post* allows the involvement of the whole class in the review of their work. Students are naturally engaged as their own posts are reviewed in the context of the posts of their classmates. There appears to be a learning advantage to the collaborative evaluation process between students (Orsmond, Merry & Reiling, 2002; Topping, 1998).

In a recent trigonometry class, the teaching of common sine and cosine values was initially approached by having the students draw 60 degree reference angles in a unit circle. The angles were then to be labeled with the appropriate ordered pairs. Once this was done, the students scanned their drawings to a Dropbox® folder. These were thought to be, in the teacher’s mind, rudimentary exercises. The teacher was under the impression that he had presented enough examples. He believed that few students would present a flawed drawing with the possible exception that the labeling of the ordered pairs might be an issue. In fact, the scans revealed that the students labeled the ordered pairs correctly (Fig 1). However, several students’ impressions of a 60 degree angle more closely resembled a 45 degree angle (images F1A – F5A in the Fig 1 folder). This was something the teacher hadn’t expected and was an important revelation. Interpretation of reasonably approximated angles in the trigonometry course is critical in a number of applications. The teacher then applied a new direction of emphasis in the teaching of triangle applications.

![Figure 1: Task: Draw 60 degree reference angles in a unit circle](image1.png)

![Figure 2: Task: Describing an architectural site](image2.png)

![Figure 3: Task: Translating a cosine curve](image3.png)

![Figure 4: Task: Translating a cosine curve after instructions on labeling axes](image4.png)
In the same class, when students were found to have difficulty with an application problem describing an architectural site, it was useful to have them draw what they thought the problem was describing (Fig 2). There was a profound advantage in displaying the collection of student perceptions and then discussing the posted results with the class. Several students had the same mistake (F2A – F2C). A couple of students had a correct diagram (F2D) and were asked how they interpreted the application. This provided the students additional perspectives from their peers on how to understand the application.

The next exercise asked the students to use their understanding of the sinusoidal-wave graph and translations to render a graphical representation of a trigonometric function (Fig 3). Most students did well at translating a cosine curve exercise but the teacher found that most students had difficulty labeling the horizontal axis (F3A – F3C). The lesson was then adjusted to emphasize methods of labeling graphs. The result was much-improved labeling of the axes in the next class exercise (Fig 4, F4A – F4C).

**Examples from Science Classrooms**

The *scan and post* technique is an excellent tool for formative assessment in science classrooms. Science teacher candidates were asked to predict what would happen if a 2-liter soda bottle were punctured at three locations while the fluid level was kept constant by “topping off” the bottle through a funnel (Fig 5). The apparatus was placed on a lab table in the front of the room, and teacher candidates were asked to draw a figure illustrating their predictions. The teacher had performed this activity for years, and had generally assumed that the teacher candidates had a good grasp of the factors influencing fluid pressure. The drawings provided much more information than a show of hands could ever show, and highlighted common misconceptions. Approximately one fourth of the teacher candidates drew a diagram similar to Fig 5A, predicting that there would be no difference in fluid pressure as a result of depth in the water column. Another quarter of the class predicted that the water streams would never intersect, as illustrated in Fig 5B. Approximately ten percent predicted that no water would flow out, as illustrated in Fig 5C. Finally, approximately 40% correctly predicted that water would flow farther with increasing depth. The instructor had performed this activity for more than twenty years, each time asking for a show of hands predicting outcomes 5A and 5D. It never crossed his mind that some students would predict options 5B or 5C. Using the *scan and post* technique, the instructor realized students held a wider variety of misconceptions than formerly imagined. At this point, the instructor gave a short lesson on water pressure, after which all of the students redrew their diagrams predicting Fig D. When the activity was performed, the teacher candidates expressed satisfaction that their revised hypotheses were correct.
Fig 6 illustrates sample results when science teacher candidates were asked to
draw diagrams that they could use to explain to their secondary school students the
reasons for seasonality on Earth. The instructor, an experienced professor of science
education, had assumed for many years that the vast majority of science teacher
candidates could explain this basic phenomenon. To his surprise, only a quarter of the
science teacher candidates produced diagrams that could be used for instruction. The
scans revealed a series of inadequacies and misconceptions. Fig 6A shows that the
teacher candidate had some understanding that the tilt of the Earth’s axis was partially
responsible for seasonality, but their diagram was so sketchy and incomplete that it would
be useless for instruction. Figs 6B and 6C illustrate a widely held misconception that
seasons are due to the elliptical orbit of the Earth. Although the Earth does travel in an
elliptical orbit, as do all satellites, its orbit is nearly circular, unlike the highly eccentric
orbits shown. Fig 6C illustrates that the teacher candidate had some understanding that
the tilt of the Earth’s axis was involved, but the diagram shows that he believed the
elliptical nature of the Earth’s orbit was equally important. Approximately one quarter of
the teacher candidates produced correct diagrams such as the one illustrated in Fig 6D.
Upon seeing the thumbnails of all explanations, the instructor realized that he would need
to address student misconceptions before he could continue with the lesson. More
importantly, this activity provided an opportunity to illustrate the importance of diagrams
during science instruction, as students critiqued each other’s diagrams from the
perspective of science learners. The scan and post technique provides science teachers
with valuable information during instruction so that they can adapt their instruction to the
needs of their students

Conclusion

The scan and post method helps promote a paradigm shift in STEM education
towards collaboration and accountability. Students can no longer hide behind their raised
hands. Instead, they must produce diagrams and solutions to illustrate their understanding.
These diagrams provide a permanent digital record that can be used by the teacher to
gauge growth in student understanding accompanying instruction. Such diagrams provide
benchmarks during instruction so that teachers can determine student skills and understanding before summative assessments are given.

The *scan and post* technique encourages metacognition as students see their predictions, drawings, and solutions contrasted with those of their peers. By examining the models of others, they are given the opportunity to reflect on their own thinking. As noted in earlier research, “These activities help students gain an understanding that the learning enterprise requires collaboration, independent verification, and peer review” (Herr et. al., 2013, p.2). The *scan and post* technique promotes student metacognition and makes possible a degree of continuous formative assessment never before possible. Teachers are provided real-time snapshots of student understanding that can be used to reform their instruction to meet real, rather than perceived, student needs.

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