CPR2: Fall 2020 Pilot

Prepared by:
SRI International
Andrea Beesley
Jared Boyce
Patrik Lundh
Carol Tate
Mindy Hsiao
Elise Levin-Guracar

SRI Education™
A DIVISION OF SRI INTERNATIONAL

SRI International • 333 Ravenswood Avenue • Menlo Park, CA 94025-3493 • 650.859.2000 • www.sri.com

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Contents

This memo includes recommendations and findings from the observations, teacher interviews, student surveys, and student assessments in fall 2020.

Overall, teachers implemented the lessons as presented in the Summer Institute, adhering closely to the materials they received. Teachers had limited time to implement the activities and needed to start with programming, so some aspects of the Collaborative Partnership to Teach Mathematical Reasoning Through Computer Programming (CPR2) instructional model were not achieved in this first lesson.

In this first lesson, students had limited time and opportunity to tinker and explore, struggle with programming and mathematics concepts, and ask questions and engage in open-ended problem-solving conversations with teachers and peers.

The modified Student Computer Science Attitude Survey functioned well; most factors displayed good reliability and students appeared to meaningfully engage with the items. No ceiling effects were noted, so there is room for student scores to improve. Questions remain about the fit of the Mathematics Assessment Resources Services (MARS) assessment as a CPR2 outcome measurement.

Recommendations

Recommendations for supporting teachers focused on technology and on connecting CPR2 to mathematics content.

- Teachers could access a central repository of recommended compilers.
- Pre-lesson checklists emphasized the importance of testing systems before the lesson.
- Teachers could be supported in creating and adapting CPR2 lessons with content that aligns to the standards they are addressing in instruction.

Recommendations to support student conceptual engagement and learning focus on shifting the cognitive work from teachers to students.

- Teachers and students need ample time to engage with the CPR2 content and practices. When teachers are pressed for time, they tend to emphasize control, lecture, and process and are less concerned with exploration, discussion, and recognizing student struggle.
- Whole-class discussions could be more student-driven and oriented around conceptual struggles and problem solving. Teachers could use strategies to elicit student thinking and address their questions.
- Students need more opportunity for tinkering and exploration, with fewer restrictions and follow-up discussions about the ideas they generate.

- Teachers could better support student engagement and learning by framing the lessons, including stating learning goals, describing how the lessons are connected to mathematics learning, and activating prior knowledge.

Lesson Observations

Background: The purpose of the lesson observations was to describe how teachers implemented CPR2, in what ways they supported student engagement and learning, and whether students participated in CPR2 lessons in ways that supported CPR2 learning objectives. An additional purpose in this year's first iteration of observations was to test the observation protocol and procedures, informing revisions for next year's observations.

Design: We developed an observation protocol that consisted of two parts: 1) time-stamped running notes to document activities, teacher and student talk, as well as notes about the learning environment and issues relevant to understanding the lesson; and 2) a debrief organized by several descriptive categories aligned with the project's constructs table. The debrief categories were based on the CPR2 instructional model, as well as other aspects of instruction that we believe support the realization of the CPR2 instructional model; for example, facilitating rich classroom discussions that allow for student questions and reasoning, checking for student understanding, addressing student misconceptions, and so on. Observers took running notes that were the basis for written summaries for each of the debrief categories.

Data Collection & Analysis: Due to COVID-19 restrictions, we conducted lesson observations virtually. Observers were able to see either the front of the classroom (usually the screen and the teacher) or the teacher's desktop. Importantly, observers did not see students and often the audio quality substantially limited the student talk observers were able to hear. Accordingly, our observation findings likely do not fully capture aspects of student engagement, teacher-student interactions outside of front-of-class teacher-led activities, or peer interactions. We observed nine teachers implementing two to four lessons for a total of 23 observed lessons. To analyze the data, we created a summary debrief of all observations for each teacher. One analyst reviewed all debrief categories across all teacher summaries and described themes and/or variations for each debrief category (e.g., to define the kinds of questions teachers asked students, or to what degree teachers provided opportunities for students to write general expressions of the mathematical relationships they discovered). The findings below summarize the themes and variations we saw across all teacher observations.

Findings

Overall, teachers delivered the Even-Odd-Consecutive (EOC) CPR2 lesson content using University of North Alabama's (UNA) provided materials as modeled during the CPR2 Summer Institute in May and June 2020. Teachers did not deliver all of the EOC lesson content due to time constraints. In particular, only one teacher reached the multiplication EOC content (e.g., even times even is even). Teachers generally delivered the EOC CPR2 lesson content using teacher-led direct instruction, not yet providing many opportunities for students to productively struggle or tinker. We generally did not observe much EOC instruction supporting students' conceptual understanding of mathematical concepts and mathematical generalization, or discussion of students' proof-writing. One teacher reviewed an example proof with the students, yet there were no checks for student understanding of the proof and no opportunities given for students to create proofs or arguments themselves. Another teacher told students, "In college a lot of mathematics includes proofs, and that's what we're kind of working on here," but classwork around proving conjectures beyond use of test cases was done by the teacher.

1. **Classroom Environment:** There were no problems observed with student behavior. The classroom environments, to the extent that we could observe remotely, seemed casual and respectful.
2. **CPR2 Instructional Model Implementation[1]:** Teachers need to identify mathematical concepts in the lesson and lead students through reflections on problems and solutions for students to learn, understand, and apply mathematical concepts, including generalization. Students can then reconstruct mental structures and organize them into novel schemas. But during observations, teachers rarely identified mathematical concepts or generalization in their instruction, nor led students through conceptual reflections. Four of the nine teachers did not do so at all, and the other teachers did so inconsistently in limited ways. For example, in one class, math concepts beyond the formal definitions of even and odd numbers were not introduced to students during the lessons. When the teachers introduced general expressions, they usually did not follow up through discussion or checks for understanding. Another teacher led a discussion about the math concepts and generalization, but it took the form of direct questioning of students with little opportunity for students to grapple with and reason through the concepts. The strongest example was a teacher who talked about the math concepts of if-and-only-if and integers as a set of numbers. The teacher and their mentor teacher talked about some of the features of even and odd numbers, general equations as necessary for proofs, and briefly about factoring.

   Teachers provided opportunities for students to write mini-programs in Python. Generally, these opportunities were narrowly constricted rather than supportive of exploring mathematical concepts or generalization. For example, in one class the teacher provided students with opportunities to write programs and encouraged them to tinker and explore but limited the parameters of their exploration ("Don't change anything else in the code except for this, right here").

   Overall, students had few opportunities to write general expressions or generate expressions to represent mathematical relationships they uncovered on their own. Teachers mostly wrote the expressions for students, followed by discussion in some

[1] The four components of the CPR2 Instructional model are: (1) Teachers clearly identify mathematical concepts/generalization; (2) Teachers provide students with opportunities to write mini-programs to explore mathematical concepts/generalization; (3) Teachers provide students with opportunities to write general expressions to represent mathematical relationships; and (4) Teachers provide students with opportunities to make conjectures and write arguments/proofs to support their conjectures.

cases, or more commonly with students simply copying the expressions down. When students did generate their own expressions, the teacher provided heavy scaffolding and we did not see evidence that students were developing deeper understanding of expressions and mathematical relationships.

Three of the teachers provided limited opportunities for students to make conjectures. We did not observe teachers providing students with opportunities to write arguments in support of their conjectures.

3. **Lesson Implementation:** Lessons generally did not include clear framing of the lesson and course goals and connections to prior lessons. Only one teacher introduced and framed the CPR2 lesson by stating goals and connections with content and or prior lessons.

   Teachers closely followed the UNA-provided slide decks and lesson plans. Many teachers appeared to run out of time to cover all the components in the lesson plan. Teachers were generally flexible and responsive to students, but overall we did not observe teachers facilitating activities in ways that explicitly supported student agency, exploration, and reasoning.

   Whole-class discussions were usually focused on teacher questions. Overall, we did not observe teachers leveraging whole-class discussions to explore concepts and student ideas and support deeper learning.

4. **Supporting Student Learning:** Across all observations of all teachers, the teacher did most of the cognitive work. This was evidenced by teachers largely verbalizing their own reasoning rather than providing opportunities for students to voice, discuss, reflect on, and drive conversations with their own ideas, thoughts, and struggles.

   Teachers primarily asked students fill-in-the-blank questions that required specific answers. We occasionally observed open-ended questions or teachers eliciting additional students' contributions, but teachers did not further elaborate on these contributions.

   Teachers employed a variety of strategies to address student struggles, misconceptions, or other challenges. One teacher encouraged students to try things out to prove if their answer worked when they provided incorrect answers. In other cases, teachers provided correct answers, struggled themselves, and provided emotional support.

   Teachers' practices to check student understanding of the content were primarily in the form of calling on students after giving them some time to consider the question and circulating around the classroom to check their work. Overall, observers did not see evidence of teachers adapting their instruction based on checks for student understanding.

   Most of the teacher feedback observers could see took place in whole-class discussions, which focused largely on correcting students' answers.

5. **Student Engagement:** Observers noted it was difficult to gauge student engagement

in the virtual environment. From what they could tell, observers believed students were curious and interested in the content and behaviorally engaged insofar as they mostly followed the teachers' instructions. Since observers could not see the students, and audio often was limited in capturing the whole classroom, it was difficult to hear whether and what questions students asked. Based on our data, student questions were infrequent and primarily procedural in nature. No observer heard student questions focused on mathematical concepts or mathematical generalization.

6. **Teacher Grasp of Content:** Teachers' grasp of the content was difficult to ascertain. Observers noted that one teacher appeared confident when talking about the content and capable of navigating student questions outside the script of the lesson. Other teachers seemed relatively confident when talking about the content as long as they stayed within the "lesson script." One teacher appeared flustered by the programming and did not complete much of the lesson.

Teacher Interviews

Background: The goal of the pilot teacher interviews was to gain insight into the teachers' experiences of planning and teaching the CPR2 lessons. We were particularly interested their sense of preparedness as well as their perceptions of student engagement and learning.

Design & Piloting Goals: The pilot interviews offered an opportunity to inform both the design of CPR2 lessons, professional development, and the interview instrument itself. We designed the protocol to elicit information about 1) how well teachers felt the summer PD prepared them to implement the CPR2 lessons, 2) what aspects of implementation presented challenges for teachers, 3) teachers' perceptions of student reactions to CPR2, and 4) teachers' future plans with regard to CPR2.

Data Collection: SRI Education staff contacted all nine teachers who piloted a CPR2 lesson in fall 2020. We were able to schedule interviews with seven of the teachers. The interviews took place over Zoom and each interview lasted about 30 minutes. Interviews were transcribed and analyzed using a combination of deductive and inductive coding. Top-level categories included context, planning, teacher confidence, student responses, and future plans. Each interview was coded by two researchers.

Findings

Teachers reported feeling well-prepared to teach the CPR2 lessons and said that students enjoyed learning how to use Python. Completing the lessons in the allotted time proved challenging, partly due to technical issues and COVID restrictions. Engagement in the generalization activities varied widely.

1. **Preparation for Teaching:** Overall, teachers felt prepared to implement CPR2 in their classrooms. All seven teachers said that meeting with their mentor, UNA, and reviewing previously provided materials were sufficient to prepare them to teach the EOC lessons. One teacher said, "I had the notes out that they provided to us. I had them out constantly while I was teaching to refer back to. I felt like it was step by step. I didn't have to figure out how things connected or how it should flow, or what order it should go in." All seven teachers used the response sheets and lesson plan provided by UNA in their lessons. In addition to those materials, three teachers made their own PowerPoint presentations to go along with the lessons. After teaching the lessons, one teacher noted, "It helped me realize that I can teach this kind of stuff if I need to. Doing it as a student and then actually teaching it is two different things. So, I'm glad that I got the opportunity to teach it."
2. **Lesson Pacing**: Teachers struggled with the pacing of the lessons and often felt pressed for time. Most teachers budgeted 3 days to teach the Intro to Programming and EOC lessons, although one teacher used 4 days and one teacher planned for four and only

ended up teaching it on 3 days. All seven teachers mentioned that it was difficult to get through the content of the lessons in the time they allotted. This was, of course, compounded by the difficulties of the unpredictability in teaching during the COVID-19 pandemic. One teacher said her hardest challenge in teaching the CPR2 lessons was "…trying to keep the pace so that you get through it, but don't make it harder on them, and let them think. I'm a type of teacher, I want to have the time to let them think and unfortunately, I struggled with giving them the time to think or knowing in my head that we don't have time to think."

3. **Connection to Standards:** Students and teachers sometimes did not see the point of focusing on even, odd, and consecutive numbers. One teacher said about the EOC lesson, "It's just that it's not anything that's in any of the standards that we've ever had to teach, and we just didn't have time… I don't really see the importance of it really, at this age." Another teacher emphasized that students pick up on the lack of alignment, "I give them something that's not related to what they were doing at the moment, it's frivolous or it's I'm punishing them by making them do extra." Another concurred, "It was just something random that we had to do. That was also a challenge."
4. **Challenges to Student Exploration:** Teachers were aware the lessons were intended to emphasize student exploration but found that time constraints dictated a more step-by-step approach. Four of the teachers described students engaging in exploration, tinkering and "trying things out." Two of the four said this did not happen until the second day because the programming instruction required them to follow directions closely. "The first day they didn't really play around with it much, but the second day, they were like, 'You can add any odd number and it's always going to be odd.'" The remaining teachers characterized CPR2 lessons as proceeding in a step-by-step fashion, with students following explicit directions and filling in the required answers on the worksheets. "…when you just feel so constrained, you're like, I need you to hurry up and get it …. It didn't have to be that way, but I've got to get to my end goal, but at the same time, the purpose of the lesson is to teach them and let them think. So, anyway, just some of the things I struggled with."
5. **Student Outcomes:** Teachers reported generally positive student responses to coding and less widespread enthusiasm for generating convincing arguments. All teachers reported that at least some of their students enjoyed the lessons. Four of the teachers said students were engaged in generating the proofs. Others said they responded to the programming but didn't like the proofs: "I think that they just liked the coding. They didn't really like the convincing argument stuff. On the first response sheet, I think, they had no idea what a convincing argument was and then after I did one with them, they just copied mine. So, I don't really think that they got into the convincing argument stuff. Just the coding." Not surprisingly, teachers described a range of engagement within their classes, "I would say I had three or four that embraced it fully and ran with it. I had

about 16 kids … I had a few, like I said, that really ran with it and then several that just said, 'I'm so sorry, I have no idea what's going on.'"

6. **Use of Compilers:** Because most classrooms were equipped with Chromebooks, teachers taught Python using compilers other than IDLE, which they felt more comfortable with. Four teachers mentioned having to find their own compiler. Four teachers said they had difficulty with the compilers they ended up choosing. One did not know how to troubleshoot unexpected issues, one did not like the website she ended up choosing, and two had to adjust the lesson based on the compiler they chose. At least three teachers used Repl.it to mixed reviews.
7. **CPR2 Future Plans:** Teachers anticipated using CPR2 in the future, with modifications. When discussing their plans to teach CPR2 lessons, teachers could imagine incorporating CPR2 into their lesson plans. Two teachers had specific plans to continue where they left off in the spring by adding integer operations to build on what students learned in the fall with the EOC lessons. Generally, when teachers talked about future plans, they spoke about the lessons as "filler" lessons between units. Three teachers mentioned that their future with teaching CPR2 lessons was too hard to predict due to the unpredictability of COVID-19.

Student Survey

Background: One of the research goals of the CPR2 study is to increase "the extent to which students feel comfortable with the programming activities and with the associated mathematics, [and] the extent to which they would be interested in similar activities in the future." We intended to measure students' comfort and interest in programming activities during the efficacy study through a student survey. Thus, we used the implementation piloting year as an opportunity to test a student survey to measure students' attitudes toward computer programming activities and content.

Design & Piloting Goals: We based our student survey on the Student Computer Science Attitude Survey.[2] This survey was tested and validated across 2010–2016 in grade 8+ students for measuring five attitudinal constructs related to computer science:

1. Students' **confidence** in their ability to learn computer science skills and solve computer science problems.
2. Students' **interest** in learning computer science and solving problems.
3. Students' perceptions of **belonging** in computer science.
4. Students' beliefs in the **usefulness** of learning computer science.
5. Students' perceptions of being **encouraged** to study computer science.

In partnership with UNA and Horizon Research, Inc. (HRI), we reviewed the survey items and concluded they were appropriate for measuring the study objectives. We collectively decided to make one language alteration to the items prior to piloting: replacing "computer science" with "computer programming." We based this alteration on our beliefs that (a) teachers are more likely to use "computer programming" language in the CPR2 classroom such that (b) students will be more familiar with "computer programming" than "computer science."

We aimed to answer three questions about the student survey in our piloting process:

1. Are the survey factors still reliable with our intended student population (which differs from the original reliability research for this instrument)?
2. Do students appear to meaningfully respond to the survey?
3. Do we have significant risk of response ceilings or floors such that intervention impacts would be difficult to determine?

Data: We obtained responses from 147 students who completed the survey and consented to have their data used for research purposes. We originally intended to compare the scores of

[2] Haynie, K.C. and Packman, S. (2017). *AP CS Principles Phase II: Broadening Participation in Computer Science Final Evaluation Report*. Prepared for The College Board and the National Science Foundation, February 12, 2017. Skillman, NJ.

students completing the survey as a pretest to those who completed it as a posttest. However, very few students completed the survey as a posttest so this was not feasible.

Findings

1. **Survey Factor Structure:** The factor structure of the original survey was broadly maintained in this administration. Three of the five factors had very good reliability with our student population, one had good reliability, and one had minimally acceptable reliability.[3] Our reliability metrics for most factors were slightly below those of the original research (see Appendix A), which may be partially due to the differences in sample sizes. We consider only one factor, Belongingness, to be potentially problematic for our study. Our reliability calculation was barely acceptable (0.65) and significantly below that of the original research (0.85). We discussed our piloting results with the original survey author, and we determined that Belongingness may not be a meaningful construct for our study given the age group of our students and the design of CPR2.
2. **Little Random Guessing:** Students appeared to engage meaningfully with the survey. We have evidence (e.g., Agree responses ranged from 17.7% to 66.7%) that few students blindly responded with the same answer choice for most or all questions, which would indicate guessing. While students usually responded with the middle-response options, there was significant use of the “Strongly” options and significant variation across items (combined “Strongly” responses ranged from 15.6% to 37.4%). Lastly, items within the same factors demonstrated variation while maintaining factor structure, suggesting students were making distinctions across items (e.g., items within the Confidence factor range from average scores of 2.17 to 2.81 on a scale of 1-4).
3. **No Ceiling or Floor Effects:** We do not have evidence of response ceiling and floor risks (when the scores are all so high or so low that the items are likely to be to be too hard or too easy). All items averaged scores between 2-3 on a scale of 1-4, suggesting there is sufficient response space to measure a potential impact of CPR2 on student attitudes related to computer programming.

[3] We consider Cronbach’s alphas of 0.80+ to indicate very good reliability, 0.70+ good reliability, and 0.60+ minimally acceptable reliability per Nunally, J.C. (1967). *Psychometric Theory*. New York: McGraw-Hill.

Student Assessment

Background: One of the goals of CPR2 is to increase "student performance in problems involving [mathematical] generalization." We intend to measure students' mathematical generalization skill during the efficacy study through a student assessment specifically designed to measure this skill. Thus, we used the implementation piloting year as an opportunity to test a student assessment.

Design & Piloting Goals: We built our student assessment using items from the MARS website.[4] MARS provides a variety of mathematics lessons, tasks, and test items for use by teachers, evaluators, and researchers. We reviewed all the posted middle school mathematics test items as well as past SRI Education mathematics research and curriculum development resources for other appropriate items. Unfortunately, finding test items that directly or indirectly mapped onto the generalization skills CPR2 focuses on was challenging. The UNA team shared that their experience with constructing grade-level appropriate generalization assessments from external validated assessments was similarly difficult.

We created our student assessment with the test items we thought would be most applicable to CPR2. We sourced five items from MARS middle school tests and one item from a prior SRI-created validated math assessment. These six items and their piloting results can be found in Appendix B. We reviewed our student assessment with UNA and HRI, and all three organizations agreed these six items were related to content addressed by CPR2, specifically:

- Mathematical generalization, including arithmetic patterns (items 1, 2, 3, 4, and 5)
- Variable representations of expressions (items 5 and 6)
- Iterative computation (items 1, 2, and 5)

We aimed to answer two questions about the student assessment in our piloting process:

1. Do the items we selected perform well with our student sample?
2. Do we have any noticeable differences between the pretest and posttest samples?

Data: We obtained responses from 122 students who completed the assessment and consented to have their data used for research purposes. Of these, 92 students completed the assessment as a pretest and 30 students completed the assessment as a posttest.[5]

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[4] https://www.map.mathshell.org/
[5] We confirmed pretest/posttest assessment administration using Qualtrics timestamps and the dates teachers delivered CPR2 lessons.

Findings

1. **Student Performance:** On the open-ended questions, few students provided the correct answers (13.9%, 18.0%, 24.6%). For the multiple-choice questions, students performed better than at random but not by large amounts (23.8%, 38.5%, 38.5%). On the positive side, there is significant room for growth in these responses (no ceiling effect). This provides us with confidence there is sufficient response space to measure a potential impact of CPR2 on students' mathematical generalization performance. However, the overall low performance on these items may indicate they are not appropriate for our study. For example, item #6 is within the realm of what CPR2 lessons could affect (variable expressions) while also being beyond the assumed mathematical content knowledge of the students (we do not want to assume students are taking/have taken algebra). Even if CPR2 is effective at improving students' skills with variable expressions, the lack of experience with translating word problems into solvable equations may prevent this item from accurately measuring students' gains.
2. **Pre-Post Differences:** We did not find any statistically significant pre-post differences in students' performance on the six assessment items using a *t*-test of mean differences.
3. **Effect of Mathematical Content.** Even if we had statistically significant pre-post differences, the implementation of the EOC CPR2 lesson in the fall raised questions regarding whether CPR2 would be a likely cause of such differences. For example, the mathematical content of item #2 is about sign changes with integer multiplication, which is similar to the even-odd multiplication generalization work from EOC. However, teachers overwhelmingly did not deliver the even-odd multiplication portion of EOC in the fall; only one teacher reached the multiplication EOC lesson. Accordingly, we would struggle to attribute any pre-post differences on item #2 to the lesson.

Appendix A: Survey Reliability Metrics

Table 1: Confidence factor piloting results

Item	Strongly Disagree (1)	Disagree (2)	Agree (3)	Strongly Agree (4)	Average
I am sure I could do advanced work in computer programming.	19.7%	40.8%	31.3%	8.2%	2.28
I have self-confidence when it comes to computer programming.	12.9%	39.5%	37.4%	10.2%	2.45
I am confident that I can solve problems by using computing.	8.2%	23.8%	57.1%	10.9%	2.71
I can learn computer programming without a teacher to explain it.	27.2%	38.8%	23.8%	10.2%	2.17
I think I will do well in computer programming.	4.8%	21.8%	61.2%	12.2%	2.81

Note: Piloting *n* = 149, Cronbach's α = 0.85. Original research *n* = 802, Cronbach's α = 0.89.

Table 2: Interest factor piloting results

Item	Strongly Disagree (1)	Disagree (2)	Agree (3)	Strongly Agree (4)	Average
I like writing computer programs.	15.6%	36.1%	39.5%	8.8%	2.41
I like to use computer programming to solve problems.	19.7%	31.3%	40.8%	8.2%	2.37
The challenge of solving problems using computer programming appeals to me.	14.3%	34.7%	39.5%	11.6%	2.48
I would take additional computer programming courses if I were given the opportunity.	17.7%	40.1%	29.9%	12.2%	2.37
I hope that my future career will require the use of computer programming.	24.5%	40.1%	25.2%	10.2%	2.21

Note: Piloting *n* = 149, Cronbach's α = 0.892. Original research *n* = 802, Cronbach's α = 0.93.

Table 3: Belongingness factor piloting results

Item	Strongly Disagree (1)	Disagree (2)	Agree (3)	Strongly Agree (4)	Average
I feel I belong in computer programming.	20.4%	48.3%	23.8%	7.5%	2.18
I feel comfortable in computer programming.	8.8%	22.4%	54.4%	14.3%	2.74
I feel accepted by my peers in computer programming.	3.4%	12.9%	66.7%	17.0%	2.97
I know a lot of students like me who are interested in computer programming.	7.5%	49.7%	34.7%	8.2%	2.44
I know someone like me who uses computer programming in their work.	10.9%	42.9%	30.6%0	15.6%	2.51

Note: Piloting *n* = 149, Cronbach's α = 0.65. Original research *n* = 803, Cronbach's α = 0.85.

Table 4: Usefulness factor piloting results

Item	Strongly Disagree (1)	Disagree (2)	Agree (3)	Strongly Agree (4)	Average
Skills used to understand computer science material can be helpful to me in understanding things in everyday life.	7.5%	36.1%	44.2%	12.2%	2.61
Computer programming is a worthwhile and necessary subject.	6.1%	30.6%	49.7%	13.6%	2.1
Knowledge of computer programming will help me earn a living.	10.9%	30.6%	50.3%	8.2%	2.56
Learning to use computing skills will help me achieve my career goals	13.6%	32.7%	45.6%	8.2%	2.48
I'll need a mastery of computer programming for my future work.	18.4%	54.4%	23.8%	3.4%	2.12

Note: Piloting n = 149, Cronbach's α = 0.853. Original research n = 802, Cronbach's α = 0.89.

Table 5: Encouragement factor piloting results

Item	Strongly Disagree (1)	Disagree (2)	Agree (3)	Strongly Agree (4)	Average
A friend or peer has encouraged me to study computer programming.	23.1%	49.7%	21.1%	6.1%	2.10
Someone in my family has encouraged me to study computer programming.	23.1%	45.6%	23.8%	7.5%	2.16
Someone I know has discussed with me the computer programming field.	15.0%	40.8%	32.0%	12.2%	2.41
Someone I know has given me the desire to study computer programming.	21.1%	49.7%	26.5%	2.7%	2.11
Someone I know has praised my work in computer programming.	23.8%	49.0%	17.7%	9.5%	2.13

Note: Piloting n = 149, Cronbach's α = 0.778. Original research n = 805, Cronbach's α = 0.86.

Appendix B: Student Assessment Items and Pilot Results

Responses for Item #1 (open-ended): "After being dropped, a certain ball always bounces back to 2/5 of the height of its previous bounce. After the first bounce it reaches a height of 125 inches. How high (in inches) will it reach after its fourth bounce?"

	Overall		Pretest		Posttest	
Responses	%	n	%	n	%	n
3.2	4.9%	6	5.4%	5	3.3%	1
8 (correct)	18.0%	22	16.3%	15	23.3%	7
20	4.1%	5	5.4%	5	0.0%	0
25	4.9%	6	5.4%	5	3.3%	1
50	18.0%	22	14.1%	13	30.0%	9
500	4.1%	5	4.3%	4	3.3%	1

Note: Overall n = 122, Pretest n = 92, Posttest n = 30. Our t-test for pre-post differences was p = 0.43. We list incorrect responses when at least five students provided the same response. 45.9% of students provided responses not included in this table.

Responses	Possible rationales for incorrect answers
3.2	Students calculated the height after four bounces, not three bounces, not understanding the height was 125 inches after the first bounce.
8 (correct)	
20	Students calculated the height after two bounces, not three bounces.
25	Unsure.
50	Students calculated the height after a single bounce, not three bounces. Alternatively, students simply multiplied the two numbers without thinking through the bouncing scenario.
500	Students understood that 2/5 is equal to 0.4 yet forgot the decimal place and multiplied 125 by 4 instead of by 0.4.

Responses for Item #2 (open-ended, bounded): "If the product of 6 integers is negative, at most how many of the integers can be negative?"

	Overall		Pretest		Posttest	
Responses	**%**	**n**	**%**	**n**	**%**	**n**
0	1.6%	2	1.1%	1	3.3%	1
1	3.3%	4	3.3%	3	3.3%	1
2	4.1%	5	3.3%	5	6.7%	2
3	24.6%	3	25.0%	30	23.3%	7
4	9.8%	12	9.8%	12	10.0%	3
5 (correct)	24.6%	30	21.7%	30	33.3%	10
6	32.0%	39	35.9%	39	20.0%	6

Note: Overall n = 122, Pretest n = 92, Posttest n = 30. Our t-test for pre-post differences was p = 0.24.

Responses	Possible rationales for incorrect answers
0	Unsure.
1	Multiple negatives can "cancel" to a positive number (e.g., two negatives have a positive product). Alternatively, students found one solution and stopped.
2	Unsure.
3	Students correctly identified that pairs of negative numbers "cancel" to a positive number, so adding a third negative number results in a negative product. However, students did not generalize this to a second pair of negative numbers.
4	Unsure.
5 (correct)	
6	There are six integers, so students selected six as the maximum number of integers that could be negative without considering the constraint (product is negative).

Responses for Item #3 (open-ended): “How many numbers between 200 and 400 begin or end with 3?"

Responses	Overall		Pretest		Posttest	
	%	n	%	n	%	n
10	4.9%	6	1.1%	1	16.7%	5
19	4.9%	6	5.4%	5	3.3%	1
20	13.1%	16	15.2%	14	6.7%	2
21	7.4%	9	4.3%	4	16.7%	5
30	5.7%	7	7.6%	7	0%	0
100	5.7%	7	6.5%	6	3.3%	4
110 (correct)	13.9%	17	13.0%	12	16.7%	5
120	6.6%	8	4.3%	4	13.3%	4
300	4.1%	5	3.3%	3	6.7%	2

Note: Overall n = 122, Pretest n = 92, Posttest n = 30. Our t-test for pre-post differences was p = 0.643. We list incorrect responses when at least five students provided the same response. 33.6% of students provided responses not included in this table.

Responses	Possible rationales for incorrect answers
10	Students correctly identified that each group of one hundred numbers has 10 numbers ending with three, yet only considered one group of one hundred numbers (e.g., 200-299) and did not consider numbers beginning with three.
19	As below yet trying to avoid double-counting a number somehow.
20	Students correctly identified that each group of one hundred numbers has 10 numbers ending with three, so 200–400 has 20 numbers ending with three. However, students did not consider numbers beginning with three.
21	As above but including 300 as a number starting with three.
30	Unsure.
100	Students correctly identified that the 300’s have 100 numbers starting with three and neglected numbers ending with three.
110 (correct)	
120	Students correctly identified that the 300’s have 100 numbers starting with three, and that each group of one hundred numbers has 10 numbers ending with three. However, students double-counted numbers with both (e.g., 303).
300	Unsure.

Responses for Item #4 (multiple choice): "What expression is the greatest when *n* is a negative number?"

	Overall		Pretest		Posttest	
Responses	**%**	**n**	**%**	**n**	**%**	**n**
n – 2	23.8%	29	23.9%	22	23.3%	7
2n	9.0%	11	7.6%	7	13.3%	4
n^2 (correct)	38.5%	47	35.9%	33	46.7%	14
n/2	18.9%	23	19.6%	18	16.7%	5
2/n	9.8%	12	13.0%	12	0.0%	0

Note: Overall *n* = 122, Pretest *n* = 92, Posttest *n* = 30. Our *t*-test for pre-post differences was *p* = 0.31.

Responses	Possible rationales for incorrect answers
n – 2	Students thought that, in general, subtraction keeps numbers closer to zero than multiplication (e.g., -4 – 2 = -6 whereas -4 * 2 = -8).
2n	Unsure.
n^2 (correct)	
n/2	Students thought that, in general, division makes numbers closer to zero without considering the sign change of n2.
2/n	Students recognized that most denominators make numbers closer to zero without considering the sign change of n2.

Responses for Item #5 (multiple choice): "In the sequence below, which expression can be used to find the value of the term in the *n* position?"

Position	Value of Term
1	0.25
2	0.5
3	0.75
4	1.0
5	1.25
n	

	Overall		Pretest		Posttest	
Responses	%	n	%	n	%	n
n – 0.75	14.8%	18	16.3%	15	10.0%	3
$\frac{n}{4}$ (correct)	38.5%	47	38.0%	35	40.0%	12
4n	26.2%	32	28.3%	26	20.0%	6
n – 1.5	20.5%	25	17.4%	16	30.0%	9

Note: Overall n = 122, Pretest n = 92, Posttest n = 30. Our t-test for pre-post differences was p = 0.85.

Responses	Possible rationales for incorrect answers
n – 0.75	Students tested only the first number in the sequence and then stopped.
$\frac{n}{4}$ (correct)	
4n	Students recognized that quarters/fourths were involved, noticed the values were increasing, and concluded that multiplying by four results in larger numbers than dividing by four.
n – 1.5	Students tested only the second number in the sequence and then stopped.

Responses for Item #6 (multiple choice): "Ten friends go out for a meal. Some friends have three-course meals and the rest have two-course meals.

A three-course meal costs $15. A two-course meal costs $12. The bill for all 10 meals is $141.

The number of people who have three-course meals is *x*.

One of these equations can be solved to find the correct value of *x*. Which is the correct equation? One of these equations can be solved to find the correct value of *x*. Which is the correct equation?"

	Overall		Pretest		Posttest	
Responses	**%**	**n**	**%**	**n**	**%**	**n**
15x + 12x = 141	25.4%	31	26.1%	24	23.3%	7
15x + 12(x-10) = 141	16.4%	20	16.3%	15	16.7%	5
15x + 12(10-x) = 141 (correct)	23.8%	29	26.1%	24	16.7%	5
(15 + 12)x = 141	10.7%	13	12.0%	11	6.7%	2
15x + 12y = 141	23.8%	29	19.6%	18	36.7%	11

Note: Overall n = 122, Pretest n = 92, Posttest n = 30. Our t-test for pre-post differences was p = 0.262.

Responses	Possible rationales for incorrect answers
15x + 12x = 141	Students recognized that two unknown quantities of people needed to be multiplied by costs, yet did not consider relationships between the two quantities nor that the quantities are not necessarily the same.
15x + 12(x-10) = 141	Students recognized the relationship between the two quantities of people, yet did not order the subtraction correctly.
15x + 12(10-x) = 141 (correct)	
(15 + 12)x = 141	As with the first option in factored form.
15x + 12y = 141	Students recognized that two unknown and possibly different quantities of people needed to be multiplied by costs, yet did not consider the relationship between the two quantities.