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Integrating Computational Thinking in Rural Middle School Art Classes in Eastern North Carolina

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With funding from a National Science Foundation (NSF) grant, an innovative endeavor to integrate computational thinking into the teaching of both music and visual arts in three rural school districts in North Carolina was launched in early December 2018. Over the next five years—a time span that encompassed a major hurricane that devastated the area and the COVID-19 pandemic—the partners in a research practitioner partnership collaborated to create and refine curricular activity system projects in both subject areas. This paper is focused on the visual arts component of the grant activities. After discussing the genesis of the project, I situate it as contributing to the cultural capital of the middle school student participants and situate it theoretically in cognitive flexibility theory. I then discuss the operational definition of computational thinking that underpinned the design of the elements of the curricular activity system, which were then refined and adapted to the rural contexts in collaboration with the teachers. I provide an overview of the curricular activities (a professional development website was created by grant colleagues at the Friday Institute at North Carolina State University) and discuss students' perspectives on the concepts and approaches of computational thinking. I close with reflections on the importance of the project.

Keywords**:** rural education, computational thinking, visual arts, music, integration

Computational thinking is arguably more readily associated with the study of science, technology, engineering, and mathematics (STEM) than with its later extension into the study of the arts (STEAM). In his groundbreaking *Mindstorms* project, Papert (1980) sowed the seeds of computational thinking by inviting children to encounter the powerful ideas that underpinned the human/computer interface. Papert conjectured that doing so would prepare them for the work environment of the future. In his foreword to the second edition of *Mindstorms* (1993), Sculley—who retired in May 1993 after 10 highly successful years as the Chief Executive Officer of Apple—praised Papert for being the premier leader in the education reform movement—one who understood that "technology in education is effective only if placed in a larger context" (p. vii).

The larger context for the grant project that is the focus of this paper was a collaboration among faculty at East Carolina University and representatives of three rural school districts in eastern North Carolina who were members of a research practitioner partnership, hereafter referred to as RPP. (Coburn et al., 2013; Coburn & Penuel, 2016). RPPs were defined by Coburn et al. (2013) as "long-term collaborations between practitioners and researchers that are organized to investigate problems of practice and solutions for improving schools and school districts" (p. 1). Even though the grant submission was oriented to enriching the educational environment in the schools rather than addressing a problem of practice, with the enthusiastic support of my East Carolina University colleague who had inaugurated the RPP, representatives from the three districts reviewed a draft of the grant document prior to convening to formally discuss its submission.

This initial meeting was notable for its cordiality even as it immediately engaged us with joint work at the boundaries (Penuel et al., 2015). Although the draft submission was oriented to science and mathematics (in response to a call for proposals issued under the umbrella of the Computer Science for All initiative), the three district representatives had independently conceived of the potential benefits of the grant in their social worlds in the teaching of visual arts and music. Our school district partners were acutely aware of the challenge that their perspective on the grant represented, but their focus on visual arts (two school districts) and music remained firm. Despite some foreboding related to the likelihood of an arts-based proposal being funded under the Computer Science for All initiative, we pivoted the focus of the grant to its new cultural orientation and flagged sections of the draft for rewriting. We settled on "iCS4All" as our abbreviation of "Integrating Computer Science and Computational Thinking in Visual Arts and Music in Three Rural Eastern North Carolina School Districts."

Theoretical Framework and Context

Rural places thrive as their own complex, rich, and dynamic social worlds. They are collectively neither "a kind of safety deposit box that stores America's fundamental values" (Lichter & Brown, 2011, p. 568) nor merely pantries and bedrooms for urban areas. Bourdieu (1986) referred to social worlds as consisting of "accumulated history" (p. 241) that, by synthesizing otherwise distinct elements of the context, constituted a form of capital that enables "agents or groups of agents . . . to appropriate social energy" (p. 241). The accumulated history of eastern North Carolina—the location of iCS4All—is inextricably intertwined with two technological innovations. The first was the purportedly accidental discovery in 1839 of the flue-curing process for tobacco (Biles, 2007). This innovation yielded a bright leaf tobacco and fueled a financial boom that enriched the 11 counties in the "Old Bright Belt" for generations (Biles, 2007, p. 158). The second innovation was the cigarette rolling machine used by W. Duke, Sons and Company—starting in the mid-1870s—to produce up to 120,000 cigarettes per day and dominate the market (Denton, 2019).

Both these innovations impacted what Bourdieu (1986) conceptualized as economic capital (assets convertible into money and institutionalized in property rights). The social world that was founded on the economic capital of tobacco-based prosperity in the Old Bright Belt began to change following the 1964 Surgeon General's report that cited the health risks associated with smoking; formerly thriving tobacco-based communities encountered financial hardship and their populations dwindled as their economic capital dried up.

According to Bourdieu (1986), economic capital can be converted—with concerted effort—into cultural capital (institutionalized in educational qualifications). Bourdieu (1977) defined cultural capital as "instruments for the appropriation of symbolic wealth socially designated as worthy of being sought and possessed" (p. 488). Of particular interest in the context of iCS4All is Bourdieu's (1979) division of cultural capital into *incorporated* cultural capital ("an individual's inherent and lasting disposition influenced by processes of formal education and individual socialization" [Sieben & Lechner, 2019, p. 1]), *institutionalized* cultural capital (entailing institutional titles), and *objectified* cultural capital ("tangible cultural goods such as books or works of art that can, in contrast to incorporated cultural capital, be physically transferred" [Siben & Lechner, 2019, pp. 1-2]).

The iCS4All endeavor was directly oriented to impacting students' inherent and lasting dispositions towards art—their incorporated cultural capital—which DiMaggio (1982; DiMaggio & Mohr, 1985) characterized as "children's exposure to cultural forms such as classical music, great works of literature, the arts, galleries, and museums" (Davies & Rizk, 2018, p. 338). The aim of iCS4All was to engage middle school students in the participating rural school districts with an enriched perspective on art through integrating technology-enabled computational thinking into their curriculum. Specifically, the aim was to integrate the concepts and approaches of an appropriate definition of computational thinking—knowledge "worthy of being sought and possessed" (Bourdieu, 1977, p. 488) because it may provide access to economic capital in the "Age of Digital Information" (Linn, 2010, p. vii)—with the creation of objectified cultural capital in the form of works of art.

Curriculum Integration and Cognitive Flexibility

Our integrative approach aligned with cognitive flexibility theory as discussed by Efland (2002) in the context of art education. Efland critiqued a symbol-processing computer analogy to the acquisition of knowledge—an analogy that might seem to be the most obvious choice in our case—as pertinent to computer science but of limited relevance in art. As Efland and the exponents of cognitive flexibility theory highlighted, some learners who are adept at acquiring knowledge in conventional instructional contexts (e.g., medical students in early stages of their education or art students) struggle when they endeavor to apply that knowledge in real-world contexts—in "complex and ill-structured domains" (p. 83). Efland conjectured that, if learners possessed cognitive flexibility—simply defined as "a quality of mind that enables learners to use their knowledge in relevant ways in real-world situations" (p. 82)—they would have little difficulty putting their knowledge into practice.

Efland (2002) sourced the roots of cognitive flexibility theory in the work of a group of psychologists (e.g., Spiro, Feltovich, Coulson, and Anderson, among others) who studied the very difficulties experienced by medical students cited above. Well prior to the work of Efland and those researchers, however, in *The Psychology of Art*, Vygotsky (1971), but written some 40 years prior to 1971, addressed the question of what transforms a human contrivance into a work of art. In Leontiev's (1971) introduction to *The Psychology of Art*, he made a particularly apposite observation in the context of iCS4All: "Transformation into a figure or symbol does not of itself create a work of art. The 'pictographic quality' of a production and its quality as a work of art are two very different things" (p. vii). Our integration of computational thinking into the visual arts classes was not oriented to the carrying out of a set of disengaged steps but to students' appreciation of the affordances of the technology in facilitating their intention. We were oriented to engaging students in that "metamorphosis of [their] feelings" (Leontiev, 1971, p. vii) that distinguishes works of art from pictographs.

Operational Definition of Computational Thinking

Shortly after Wing (2006) characterized computational thinking as "a universally applicable attitude and skill set" (p. 33) in her three-page article published by the Association of Computer Machinery, the National Research Council (NRC, 2010) featured Sussman's depiction of "computational thinking-as-basic-language" (p. 15) among many other conceptualizations. Grover and Pea (2013) wryly remarked that the multiple conceptualizations of computational thinking at the NRC workshop the very diversity "threw into sharp relief the lack of consensus that seems to have bedeviled this space" (p. 39).

To facilitate the implementation of iCS4All, my colleagues and I sought a definition that was oriented to computational thinking-as-basic-language while offering a clear path to operationalization. We found such a definition in a conceptualization of computational thinkers as well versed with the concepts of logic, evaluation, algorithms, patterns, decomposition, and abstraction and skilled enactors of the processes of tinkering, creating, debugging, persevering, and collaborating (*Barefoot*, 2020). The *Barefoot* (2020) initiative was set up in the United Kingdom in 2014 to empower "primary school teachers in the UK to deliver the computing curriculum brilliantly with free workshops, helpful online guides and engaging lessons" (https://www.barefootcomputing.org/about-barefoot, para. 1). Despite the intentional orientation of the *Barefoot* definition to younger children, as shown in Table 1, the concepts and processes are relevant far beyond the age of younger children, and the alignment of the components of the definition with the conceptualization of computational thinking-as-basic-language is apparent.

Implementation

The plan for iCS4All was that I would lead the creation and collaborative refinement of some eight or so approximately month-long extended curricular activities (Reardon & Webb, 2019) and share these with the teachers for them to implement—adjusting them as appropriate. In putting the plan into action, one or both of my colleagues from the East Carolina University computer science department who were involved with iCS4All and at least one of the graduate assistants working on it drove with me monthly to visit with all three of the teachers who gathered at one of the schools on a rotating basis. I referred to these meetings as Moderation Meetings since the idea was for them to bring student work with them to illustrate the viability of the activities as designed or as they had moderated them. Those in-person meetings were crucial to the implementation of the grant.

The teachers filtered each curricular activity through their intimate knowledge of the local community and what would "work" in the environment in which their students thrived. The following anecdote illustrates how easily our assumptions from our East Carolina University perspective could be jarring in the local context.

When I picked-up the rental car for the almost two-hour drive for our first visit to one of the school sites, I was taken aback to be given the keys to a brand-new, bright yellow sports car with a very loud exhaust. (At that time, East Carolina University had an agreement with a car rental firm for faculty travel.) I pleaded for something a little less conspicuous, but there was no other car available.

Table 1

Components of Computational Thinking

Concepts		Processes	
Logic (predicting and analyzing)	Logic helps us to establish and check facts and make predictions.	Tinkering (experimenting and playing)	Tinkering means trying things out through experimentation.
Algorithms (making steps and rules)	An algorithm is a precise sequence of instructions, or set of rules, for performing a task.	Creating (designing and making)	Creating is about planning, making, and evaluating things (e.g., animations, games, or robots).
Decomposition (breaking down into parts)	Decomposition is breaking a problem or system down into its parts.	Debugging (finding and fixing errors)	Debugging is about finding out what is wrong in an algorithm or program and fixing it.
Patterns (spotting and using similarities)	By spotting patterns, we can make predictions, create rules, and solve other problems.	Persevering (keeping going)	Persevering is never giving up, being determined, resilient, and tenacious.
Abstraction (removing unnecessary detail)	Abstraction is identifying what is important and leaving out detail we do not need.	Collaborating (working together)	Collaborating means working with others to ensure the best result.
Evaluation (making judgment)	We use evaluation when we make judgements based on different factors, such as design criteria and user needs.		

Note. Table 1 reformatted from the explanation of the terms in the *Barefoot* classroom poster available at https://www.barefootcomputing.org/docs/default-source/default-document-library/cas-computational-thinking-key-term-cards.pdf?sfvrsn=942592ea_0

When we arrived at the school—closely abutting the county highway on the outskirts of the nearby town and directly across from an extensive corn field—I was disconcerted to see the entry to the visitor's parking directly off that county highway blocked by several large traffic cones. Obviously, there must be another entry further down the highway, I reasoned. After I turned in, however, I realized it was the bus entry and gave access to the back of the school building. I made a sedate turn, hoping that the thrumming growl of the sports car's engine would not distract too many students in the adjacent classrooms, and drove back onto the county highway. At that stage, my companion suggested that he should move the cones so I could drive in through the obvious entry. While he replaced the cones, I parked the car in one of the visitor's spots. We reported to the front office to find that we had triggered a trespass alert to the sheriff's office! We clearly were not "locals" because "everybody" knew that the (completely unmarked) entry into the visitor's parking involved turning off the county highway just before the adjacent church building and driving down the access lane behind it.

Grant Details

As discussed above, we named the National Science Foundation grant (No. 1738767) that funded our project "Integrating Computer Science and Computational Thinking in Visual Arts and Music in Three Rural Eastern North Carolina School Districts" (iCS4All) toward the end of the initial meeting with the representatives from our RPP partners. Mindful of the warning issued by Roschelle et al. (2010) that "new technologies must address the core curriculum or face certain marginalization" (p. 239), we integrated the components of our visual arts curricular activity system projects with the participating teachers' implementations of the North Carolina Essential Standards Visual Arts Eighth Grade—especially the standards that address visual literacy (8.V.1–8.V.3; https://bit.ly/3m8wxSM).

We intended that the students would continue to develop the digital literacy they had already acquired during their elementary school years in the participating districts (Spires & Bartlett, 2012). In addition, through their teachers' participation in the professional development and ongoing support that we provided as part of iCS4All, we intended that the students would develop enriched understandings of the subject matter by virtue of their teachers' integration of the concepts and approaches of computational thinking into their classes. Lastly, we intended that the principals of the two schools and the students' parents would be invited to engage with appropriate elements of the curricular activity system components and contribute to their refinement. Our overarching research question was: To what extent can computational thinking be integrated with visual arts teachers' customary teaching practice and be inculcated by their students?

Curricular Activity System Components

With substantial input from one of the art teachers and two graduate assistants, we developed and refined 12 curricular activities, as shown in Table 2. The computational thinking concepts/approaches (see Table 1) that were the main foci of each activity (listed roughly in order of priority) are listed in the third column together with the non-standard materials (including technological software/hardware) that our students used. (A wide range of non-standard materials could be used instead of those listed—particularly technological software/hardware.) The activities are not inherently sequential, but the later activities are more demanding, and it would seem best to maintain the first and last activities as "bookends."

Table 2

Curricular Activities for Visual Arts

Title	Description	Concepts (C) Approaches(A) Materials (M)
Introducing Computational Thinking in the Art Room	An introduction to computational thinking terms.	C: Logic, Patterns A: Tinkering, Persevering, Collaborating M: Dollar Store-type puzzles (~25-50 pieces), CoSpaces
Kandinsky: Elements of Art & Principles of Organization	Create cut paper designs inspired by Wassily Kandinsky and then analyze them according to the elements of art and principles of organization	C: Algorithms, Decomposition, Evaluation, Abstraction A: Tinkering, Debugging, Creating, Persevering M: Adobe Fresco
Ready, Set, Go	Explore pattern recognition and create their own game puzzle.	C: Algorithms, Patterns A: Tinkering, Collaborating, Persevering, Creating M: Chromebooks, Google Draw, http://www.setgame.com/set/puzzle
Symbolic Portraits	Create a self-portrait layered with symbolic imagery	C: Algorithms A: Creating M: Personal cell phones, Printer, CoSpaces
Layers of Meaning: Palimpsests	Learn about palimpsests and use the idea of layering on a musical score as a canvas by embedding symbols in the score using color and line.	C: Algorithms, Logic, Patterns, Evaluation A: Creating M: Cricut, Printer
Digital Mondrian	Transform an image from Realism to Abstraction using software.	C: Abstraction, Decomposition A: Creating, Debugging M: Chromebooks, Google Draw, Printer
Graffiti & Contemporary Street Art	Explore typography, graffiti and contemporary street art and create their own personalized messages.	C: Algorithms, Decomposition, Patterns, Abstraction, Evaluation A: Tinkering, Creating, Debugging, Persevering, Collaborating M: Adobe Fresco, Wide-Format Printer

Title	Description	Concepts (C) Approaches(A) Materials (M)
Photography	Study work of famous photographers to uncover what creates a compelling photographic image then create their own photographs, documenting their world.	C: Decomposition, Abstraction, Evaluation A: Tinkering, Creating, Debugging, Persevering M: iPads/Personal cell phones, Picture editing apps (e.g., Distress FX), Printer
I Am From . . . Sights of Home	Create a mixed media portrait of where they are from.	C: Decomposition, Patterns, Abstraction, Evaluation A: Tinkering, Creating, Debugging, Persevering, Collaborating M: Maps, Yarn, Needles, iPads, Printer
Moving Pictures & Claymation	Learn about the history of film then develop their own animated films using clay models.	C: Logic, Decomposition, Abstraction, Evaluation A: Tinkering, Creating, Debugging, Persevering, Collaborating M: iPads, CoSpaces
Tactile Picture Books	Create 3D images based on children's stories and assemble into a tactile picture book that could aid a person who is visually impaired.	C: Logic, Algorithms, Decomposition, Abstraction, Evaluation A: Tinkering, Creating, Debugging, Persevering, Collaborating M: iPads, Tinkercad, Thingiverse, 3D Printer
Culminating Activity: Personal Visual Arts Portfolio	Compose and narrate a personal portfolio of curricular activity artifacts.	C: Logic A: Persevering M: iPads, CoSpaces

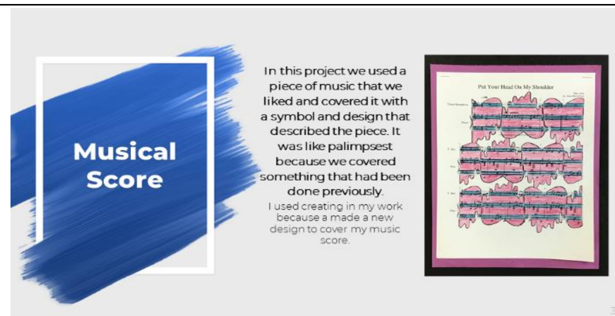
Note. A professional development website for teachers who are interested in pursuing the integration that iCS4All explored is on the PLACE website (see "iCS4All Art" and "iCS4All Music" at https://place.fi.ncsu.edu/) maintained at North Carolina State University.

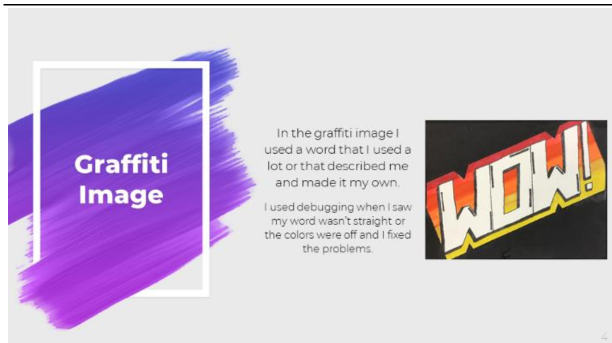
Evidence of Effectiveness

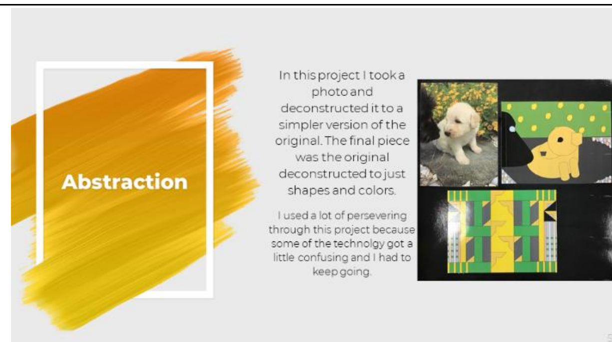
An early decision that we and the teachers agreed upon was that we were not intending to assess the accuracy of students' recitation of the contents of the definition of computational thinking. Whenever the students saw the key words, they also saw the thumbnail definitions of them. However, as shown in Table 2, the introductory curricular activity was designed to engage students with each of the six concepts and increase their awareness of the relevance of the five approaches to their learning of art as well as to their other school subjects. Our intention was to demystify otherwise arcane terms such as "algorithm" (referred to by one of the teachers as "a daunting term"). We assessed the effectiveness of the students' grasp of the concepts of computational thinking (see Table 1) by their reflections on their artwork and by gaining insight into their understanding of the six concepts by conducting focus groups. As shown in Table 2, the culminating activity was for the students to construct a portfolio of their work over the course of the year. Table 3 shows the artwork of eight projects from one student and her reflections on each project.

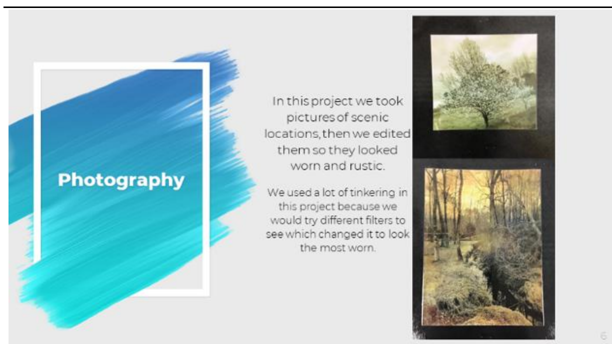
Table 3

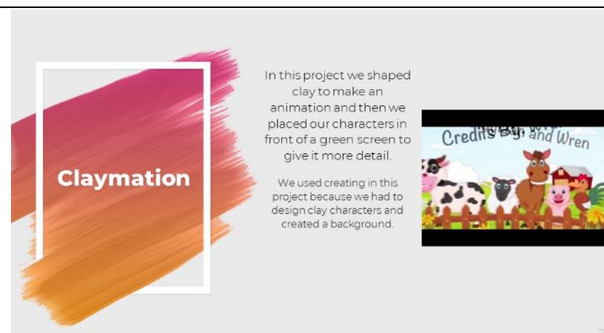
Project Portfolio

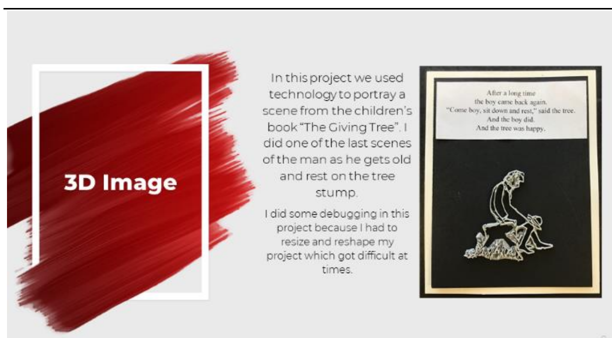


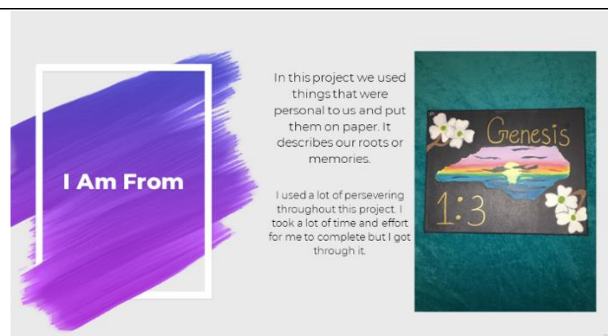












The teachers invited six students to participate in video-recorded focus groups that were conducted approximately a month apart by graduate assistants working either individually or in pairs. I met with the graduate assistants prior to the first focus group to discuss logistics of setting up the meeting room and the process of conducting a focus group with this age group of participants. Although both the graduate students and focus group participants were nervous at first, everyone became more familiar with the process, the young students shared their perspectives freely. For example, in a later focus group, students were invited to comment on the concepts of computational thinking invoked in the *Barefoot* definition by responding to focus group prompts that did not use the names of the concepts directly. Table 4 provides a synthesis of responses (the *Barefoot* term is in parentheses in the left-hand column; quotes indicate a particular student's exact words).

Table 4

Synthesis of Perspectives on the Concepts of Computational Thinking

Prompt	Synthesis of Responses
(Logic) To what extent do you make predictions about what is going to happen in art?	All the time. The artist has to work with shapes and symbols and they make predictions that a certain placement will work. But they can't know for sure how things will look until they have placed them. The same with colors. It's like experimenting. You put two colors next to each other and if it works you keep it.
(Algorithms) To what extent do you follow a set of rules for doing something in art?	We like to be free. We follow the guidelines, but there are plenty of "empty boxes [in the guidelines] that you have to fill in yourself." We do our own thing for the most part—just follow the general idea. Some things must be done in order (e.g., in creating a watercolor).
(Decomposition) To what extent do you break a problem down into simpler parts in art?	In the *Layers of Meaning* project, it was too complicated to create in a single step. For example, we had to make a grid, then place all the self-chosen symbols, sketch out the face, use a Sharpie to make the face stand out against the symbols, and then implement your color scheme. We had to break the image of our faces down into parts too.
(Patterns) To what extent do you use your ability to spot repeated designs in art and use them?	Patterns are lines or circles or squares and we just repeat them. Emojis are patterns. Sometimes we write about a topic and then choose a symbol that is in sync with what we write. For example, in the *I Am From* project, "I chose a heart."
(Abstraction) To what extent do you leave out details and focus on the "big picture" in art?	Don't focus on the details. "I was looking for a way to show integrity and chose this [holds out both hands one just above the other with palms facing]."
(Evaluation) To what extent do you make judgements about your work in art?	We compare it to [the teacher's] example or how it looks to us. We never expect ours to look as good as [the example] or compare it to a friend's. "Mine's just a little bit ugly. I want to throw it out the window, it is so ugly." "I had to make my jaw-line look a bit better and not hanging."

In general, I liaised with the teachers to ascertain what curricular activity the students were working on and then met with the graduate assistants in the week prior to the focus group sessions to decide on open-ended prompts related to that project. For example, after *Digital Mondrian* (see Table 2) students were asked

Tell me about the *Digital Mondrian* project. Was it interesting?

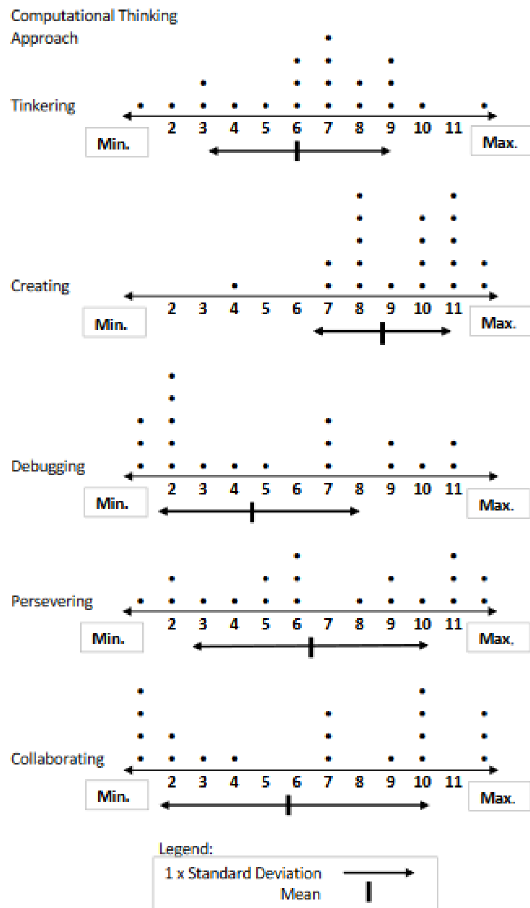
- Would you like to show it to me so you can tell me about it more effectively?
- What was the biggest challenge?
- What would you do differently if you had the chance to do it again?

In terms of the approaches that students adopted, we gained formal insight by inviting them to place a mark on a paper copy of continuum lines drawn underneath the names of the approaches to show the extent to which they utilized each of the approaches. Each of the continuum lines were labelled simply “not at all” at the left-hand end and “to a great extent” at the right-hand end with no intermediate dividing lines (to leave students more freedom). When we received their responses, we superimposed an evenly spaced numbered line and transformed each student’s response to a stacked “dot” on a Microsoft Excel spreadsheet, as shown in Figure 1, to produce a frequency distribution. The mean was indicted on an additional double-headed arrow underneath each frequency distribution with the length of the arrow indicating the standard deviation of the students’ responses. In this way, the teachers were provided with a completely visual sense of how the students used the approaches in each curricular activity system project.

The focus group meetings and the approaches feedback forms gave us an ongoing sense of how the students were experiencing the computational thinking elements that were embedded in the various curricular activity system projects. The formal feedback channels confirmed the teachers’ everyday observations that the students’ engagement was consonant with the design of the projects and sometimes led students to deeper insights. One example related to the Layers of Meaning: Palimpsests project (see Table 2). Students were invited to conduct their own research into what a palimpsest is before they set about constructing a layered product of their own. In a subsequent focus group, one of the students complained heartily about being expected to overlay their initial artwork with a second layer of artwork: “I had to make a mess of my own work.” They were invited to reflect on why palimpsests emerged and the political or religious factors that medieval scribes might have considered in selecting parchments (palimpsests, in general, do not contain complete sets of original writing) to be overwritten (e.g., discredited religious texts, outdated account records). This invitation transported a very intelligent student into a consideration of a social order very different from their own.

Figure 1

Student Feedback on Approaches Adopted



Reflections and Recommendations

In Leontiev's (1971) introduction to Vygotsky's *The Psychology of Art*, he pondered how to achieve the metamorphosis of feelings that distinguished works of art from pictographs. He asserted that "the nature of the process itself is hidden from the investigator, just as it is concealed from the observations of the artist" (p. vii). Sussman (NRC, 2010) depicted a skillful poet who, seeking to induce an emotion in the reader, "takes pieces that have parts of that emotional state, [and] puts them together in the right way . . . so as to make a larger structure that has that property" (pp. 15–16).

We adopted the operational definition of computational thinking developed in conjunction with the ongoing *Barefoot* project in the United Kingdom (Computing at School, 2020). Although oriented to early years students (up to 11 years-of-age), we believed that the *Barefoot* concepts and approaches provided us with a robust supportive framework for the curricular activity system (Roschelle et al., 2010) that we envisaged creating at the middle school level (Reardon & Webb, 2019). As Roschelle et al. (2010) discussed, the use of the word "curricular" conveyed that our project was intentionally designed as a learning progression, the word "activity" highlighted that the components of the curricular activity system were activities in which both the teacher and the students engaged, and the word "system" adverted to the fact that we envisaged "an aligned set of related components that coherently support the . . . curricular activities" (p. 239).

We consistently focused students' attention on the fact that the digital technologies integrated into the curricular activity system components enhanced their ability to respond artistically and facilitated their ability to both demonstrate and develop their visual literacy. As Lodi (2020) recently pointed out, there continues to be little agreement among proponents of computational thinking regarding the definition of the term. Nevertheless, Lodi distilled some common themes and suggested that computational thinking involves technical and practical expertise but also includes a computational thinker's possession of a range of mental attributes such as "creativity, collaboration, tolerance for ambiguity, [and] resilience" (p. 113)—all subsumed under the concept of "transversal competencies" (p. 113).

We concurred with Ioannidou et al. (2011) that middle schools are ideal contexts for increasing and broadening participation in computational thinking because students at this stage are "reaching conclusions regarding their own skills and aptitudes" (p. 3). Middle school has been acknowledged for decades as a challenging time in the development of adolescents (Eccles & Roeser, 2011; Goldstein et al., 2015; Lord et al., 1994; Simmons & Blyth, 1987). During middle school, students are experiencing major physical and psychological changes while they are also facing social challenges and dealing with issues of identity formation. The transition from elementary to middle school can be anxiety-inducing and Goldstein et al. (2015) found that higher transition stress was associated with problematic academic outcomes including lower grades, higher school anxiety, and lower school bonding.

In the long term, sub-optimal academic outcomes are also problematic in that, according to Carolan et al. (2015), middle school performance is a predictor of the student's overall achievement for the rest of their educational career—a student whose grades begin to decline in middle school is more likely to have worse grades in the future as well as facing behavioral and social challenges. It is important to note that student achievement outcomes are impacted by more than students' personal contexts. Carolan et al. found that classroom environment and the quality of classroom instruction played a major role in student performance outcomes. They asserted that the socioeconomic status of the family and the available resources of the school district modulate the educational context—both factors were major considerations in establishing iCS4All.

In closing, we contend that our approach to integrating computational thinking with the teaching of visual arts in iCS4All boosted students' transversal competencies (Lodi, 2020, p. 113) and will increase the likelihood that the benefits will outlast the duration of iCS4All. In this vein, President Obama's vision was translated into action in the synopsis that prefaced the Computer Science for All grant solicitation site on the National Science Foundation (NSF, 2020) website by referencing "research-practitioner partnerships (RPPs) that . . . provide . . . preK-8 teachers with the instructional materials and preparation they need to integrate CS [computer science] and CT [computational thinking] into their teaching" (para. 1).

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