Developing Computational Thinking through Project-Based Airplane Design Activities

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Abstract*-*This **study investigated the outcome of project-based, airplane design activities on promoting computational thinking** (Cl) in **sixth g1·ade students in the context of anintegrated STEM learning environment. A cuniculum unit of airplane design activities was implemented in a sixth grade classroom over 10 days. The students' CT skills measured by the Bebras Challenges were significantly improved afte1·their completion of the airplane design cmTiculum unit.**

Keywords--computatio11al th.i11king, i11tegrated STEM, computi11g education, e11gineering design, project-based learning

I. INIRODUCTION

Computational thinking (CT) is a fundamental skill that involves problem fonnulation, problem-solving and scientific reasoning [1]. The integration of CT in elementa1y ClllTiculum has the potential to improve student learning of subject content and problem solving [2]. This study, a sub-study of a large research project, focused on CT in sixth graders within the context of an integrated STEM learning environment. Specifically, this study aimed to investigate the outcome of project-based, aiiplane design activities on sixth graders' CT skills after they hadpaiticipated in a ClllTiculum unit centered on aiiplane design activities. The underlying rationale of this study was consistent with that of the cunent reseai·ch on computing education, which is teaching and leaining computing skills such as CT does not necessarily involve computers or coding [3].

II. LITERATURE REvIEw

Integrated STEM was defined as an integration to facilitate students working on complex tasks "that requiI·e students to use knowledge and skills from multiple disciplines" (4) (NAE & NRC, 2014, p. 52). This approach was intended to teach STEM in a connected manner with real world problem solving. Many studies have repmted proinising benefits of an integrated approach [2] (5]. In US elementa1y schools, teachers are responsible for multiple subject ai·eas and an integrated ClllTiculum has a practical value to teach and engage students in computing and computational thinking.

Integrated STEM lea1ning hasbeen beneficial not only for computing education but also for engineering design especially for pre-college students [6]. For example, an integrated STEM leaining environment could facilitate in applying engineering design processes with young leai11ers that helped children learn and practice CT skills in [7]. Hynes and colleagues' study also provided an example of what engineering thinking and CT would look like for young students while applying vaiious disciplinary knowledge dming design activities.

Project-based leaining (PBL) engages students in constrncting knowledge and learning skills through an extended pe1iod centered around solving real world problems [8]. In PBL, leaining activities and objectives are driven by an overall guiding question with students showcasing their products often through a final competition. The PBL approach with hands-on activities allows students to investigate relevant problems, which is consistent with best practices (e.g., inquiry-based activities) for STEM lea1ning [9]. For example, instead of teacher's lecturing about the relationship between music and mathematics, students cai1 be guided to compose music to discover the connections for themselves. PBL is also one of the most adopted approaches to integrating CT in vaiious content subject ai·eas [10].

Yang and colleagues explored the practiceof CT with upper level elementaiy students in a project-based, integrated STEM leaining environment in an afterschool setting and pointed out that the practice of CT bystudents seemed to be closely related to specific leaining tasks [6]. Their study also called for finther investigation of such association. Therefore, this study focused on the investigation of CT in sixth grade students after they had paiticipated in a unit of PBL guided aitplanedesign activities in the context of an integrated STEM leaining enviromnent in a fonnal classroom setting, which required students to apply the subject knowledge of engineering, science, mathematics and technology as well as CT to solve a design challenge. The reseai·ch question guiding this study was: Could integrated aitplane design activities guided byPBL promote computational thiitking in sixth grade students in a fonna1classroom setting?

III. THEORETICAL FRAMEWORK

The authors chose eleven CT components as the foundation for this study based on relevant literature (e.g., **[11]** [12] [13]). The components were: a) CT vocabulaiy such as variables,

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modeling, testing and debugging; b) Abstractio as sense making through reducing complexity and generahzmg from specific instances; c) Algorithm as applying set of tools or sequence of steps to solve problems; d) Co cahon as desciiptions supp01led by graphs, visuahzat10ns, and computational analysis; e) Conditional logic as using strategies to clarify problems and solutions; f) Data collection as gathe g data to define or solve a problem; g) Data st11.1ctures, analysis and representation as exploring data to find patterns, causes, ti·ends, or results tofacilitate problem solving; h) Decomposition as simplifying problems or specifying steps to solve problems; i) Heuristics as applying experience-bas_ strategie.s that facilitates problem solving; j) Pattern recogrutlon as recogruzmg repeated patterns; k) Simulation and modeling as m pulating data or concepts through conti·olled programs or exercises.

Subsequently, these CT components (see Table 1) were embedded in the airplane design activities by the research team iliat consisted of an interdisciplinaiy group of researchers from educational technology, engineering, and mathematics education. The au.plane design activities further were aligned with the cuniculum standards. The aligrunent between the design activities and ilie content standards of science, engineeiing and technology was detennined by ilie teacher teaching the specific grade level.

TABIEl CT EMBEDDED IN THE BRIDGE BUil.DING PROJECT

CT Component	Desniption
CT vocabulary and tenninology	Such as variables, data, modeling, testing and debugging, iterative [11] [13]
Abstraction	Reducing complexity and generalizing from specific instances to makesense of things. The abstraction process allows building complex designs and large systems [14] [1]
Algorithm	Applying specific set of tools or sequence of steps (processes) to solve problems [15][16]
Communication	Written and oraldescriptions supported by graphs, visualizations, and computational analysis [17]
Conditional logic	Using strategy such as an "if-then-else" construct to clarify problems andsolutions [1]
Data collection	Gathering data to define or solve a problem [18][19]
Datastructures, analysis and representation	Exploring data to find patterns, causes, trends, or results to facilitate the knowledge construction and problem solving [19][18]
Decomposition	Simplifying problems or specifyingsteps to solve problems [20]
Heuristics	Applying experience-based strategy that facilitates problem solving, such as "trial and error" [16]
Pattern recognition	Recognizing repeated patterns such as iteration or recursion [12] [19]
Simulation and modeling	Manipulating data or concepts through controlled programs or exercises or creating such programs for data manipulations [18]

IV. METHOD

The study pai1icipants consisted of51sixthgraders from_two classes at a suburban elementa1y school. The PBL gmded cuniculum unit consisted of eight au.plane design lessons for 10 days, geared towards developing CT and problem-solvingskills as well as student leai1Iing about how forces (drag, thrnst, lift and gravity) work on an aitplane. Table II lists the learning objectives in the f01m of guiding questions and specific sn1de t activities regarding the aitplane design. The smdents worked m small groups of four to five smdents, and two teachers le? and facilitated tl1eiJ.· own class. Both teachers hadbeen tramed m CT and the content of the aitplane design activities, and had facilitated a longer version of the PBL cuniculum unit in an eight-week afterschool program with small groups of 4th to 6th grade students theprevious semester [6].

TABEL II. STIJDENT AIRPLANE DESIGN ACTIVITIES

Date	Guiding Question	Activity
Day1	I. How do aitplanes fly? How do teams solve problems?/ What makes a good team?	• Team building • Introduce theAitplane Design Unit • Review CT components
Day2	What makes an aitplane fly?	• Create a hypothesis about whatmakesanaitplanefly • Creating a paper aitplane prototype • Test prototype • Debrief on successes and failures
Day3	I. What are the four forces of flight? 2. How do wings keep an aitplane in the air?	• Recap Day 2 Activity • Introduce 4 Forces ofF1ight • Explore center of gravity • Explore Bernoulli's Principle on flight • Explore a wing's role in fli!!ht
Day4	I. What is theBernoulli principle? 2. How does the angleof attack affect lift and drag?	• Recap Day 3 activities • Work Stations (Bernoulli Principle, Center of Gravity, *Wmg* Cross-Section, 4 Forces Reinforcement, and Aimlane Parts)
Days	How doeschanging the angle of attack affect the lift and drag of an aitplane?	• Recap Day 4 Activity • Build glider/prototype/Test glider • Revise the design/Change angle of attack
Day6	How canwe make an aitplane stable?	Same as above
Day 7 & 8	How canwe build an aitplane that flies the farthest?	Same as above
Day9	Same as above	Same as above
Day10	Determinethe best aitplane	Final contest

Dming the first session of the PBL miit, the teachers intluduced the leaniing objectives, dtiving question andpmpose of the unit. Most itnp01lantly, the teachers explained the Problem Solving Process Cha1l (PSC) (see Figme 1) iliat mapped CT with the problem-solving and engineering design processes and activities [6].

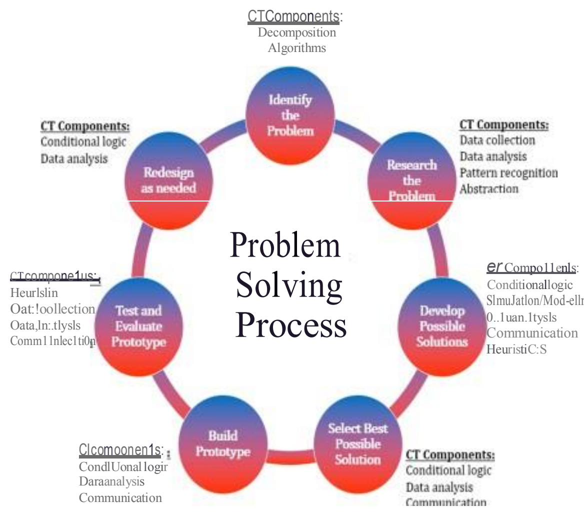

Fig. 1. Problemsolving chart.

Various CT components (Table 1) were covered and practiced dwing various design and inquity activities in the lessons. For example, abstraction was practiced when students needed to apply the the01ies of forces dw-ing the design of an airplane and its wings. Communication and data analysis were practiced when students needed to test and revise their airplanes.

A Bebras Challenges test consisting of 10 problems with different tasks [21] was administered to all students before and after the cuniculum unit. The Bebra.s Challenges examined students' logic and CT skills through different types ofproblems with three levels of difficulty which was frequently adapted by researchers to measure elementa1y students' CT [22]. The examined logic and CT skills in the test were closely related to what the airplane design unit/cuniculum focused on. The challenges took about 35 minutes to finish. 39 sn1dents completed both tests.

V. RESULT ANDIMPLICATION

Data analysis showed that the student CT skills were significantly improved (p=.04) after completing the anplane design unit activities. Table III summarizes the students' CT as measured by the pre- and post-challenge test. The results demonstrated that for those paiticipants the PBL and integrated ai1plane design activities helped not only teaching the subject content knowledge but also provided an opportwrity to learn and practice CT. The anplane design activities integrated with CT seemed to help students better solve the design challenges as students practiced vai·ious CT components dming decomposition of the problems and finding solutions.

It is interesting to note that although the anplane design activities guidedby the PBL approach were not focused on logic and algorithms like coding or programming activities, such design activities do help sn1dents learn CT components like conditional logic as tested by the Bebras Challenges. This finding would help reseai·chers expai1d CT integration beyond the usual coding and programming to a non-coding and programming approach.

TABLE III. PARTICIPANTS' PRE-AND PoST-CHAllENGE PERFORMANCE

Pre-Challe.nge				Post-Challenge			
Min	Max	M	SD	Min	Max	M	SD
	7	4.28	1.67		9	4.75	1.99

The study has limitations. First, the Bebras Challenges test focuses on logic and pattern recognition and is not fully representative of all the CT components embedded (see Table 1) in the cm1iculum unit. Second, most smdents had not been trained in completing questions like the Bebras Challenges, which 1night also help explain the low means for both the pre-ai1d post-challenge perfonnance. Students' wifamiliaiity with the type of challenge questions 1night have particulai-Iy affected students' perfonnance on the pre-challenge test (their first time encountering such questions).

Given the increasing popularity of integrating CT in elementaiy cw1iculwn, this study has impo11ant implications for integrating CT in K-12 education, especially for computing education and engn1ee1ing education. The study shows that it could be feasible to achieve a complex learning goal of computing education and engineering education via project-based leaillll1g forelementaiy students.The study fills a reseai·ch gap of using PBL guided engineering design activities to develop CT in sn1dents.

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