A Standard Decomposition Process to Inform the Development of Game-Based Learning Environments Focused on Computational Thinking

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ABSTRACT
This study describes a standard decomposition process, which is designed to decompose content standards into observable components that might illustrate computational thinking skills. These components will be integrated into an online game-based learning environment as evidence of learning (EoL) and mastery (EoM). Focusing on three computer science standards, we describe how the standard decomposition process was used to generate standard decomposition tables. We show samples of the content of these decomposition tables and describe how these tables evolved based on educator feedback.

KEYWORDS
Computational thinking, Design-based implementation research, Game-based learning, Middle grades

1. INTRODUCTION
The definition of computational thinking (CT) has evolved over the last several decades. In early work, Papert (1972) generated the term CT to describe children's learning during programming experiences. More recently, Wing (2006) broadened the definition of CT to include students' thought processes. Jansen et al. (2018) concluded that CT provides people with a method to restructure complex real-world problems into systematic and well-structured problems and supports people in designing solutions that can be manipulated by machines or humans. Grover and Pea (2013) further built on this perspective, stating "CT's essence is thinking like a computer scientist when confronted with a problem" (p. 39). Similarly, Aho (2012) considered that CT assists people in representing the solutions for solving complex problems as computational steps and algorithms. In this study, we adopt the CT definition as: a thought process (including a set of thinking skills) that occurs when students are confronted with a problem that can be formulated into steps and the solution can be executed by humans or machines.

Most CT research focuses on programming-based environments. For example, Kazimoglu et al. (2012) had students design a program to control a robot. Brennan & Resnick (2012) used Scratch (a visual programming language) to develop CT skills, and Basawapatna et al. (2011) designed CT games. Many tools are available for educators to teach students how to code and write programming languages. In our study, we extend this work by defining CT skills more broadly and encouraging students to practice and make connections between CT skills.

We use an online game-based learning environment to provide middle grades students with unique learning opportunities focused on CT. Game-based learning offers unique affordances for "stealth" learning (Sharp, 2012). For example, when playing games, students experience a state of flow (Csikszentmihalyi et al., 2014), which contributes to immersive learning experiences while playing. CT education researchers are working to extract and quantify these learning experiences to understand if and what students are learning during immersive gameplay (e.g., Grover et al., 2015; Grover et al., 2017).

Immersive game-based learning environments are innovative, covert ways to assess students' learning. The assessment information gathered within game-based learning environments could support teachers in tailoring student learning experiences based on students' needs. In this study, we use the terms **Evidence of Learning (EoL)** and **Evidence of Mastery (EoM)** to describe observable behaviors to show students are progressing toward mastery (i.e., EoL) or show evidence of mastery (i.e., EoM). In our study, game developers will use this information to design learning experiences and integrate them into an existing commercial game. The most salient evidence of students' learning will be extracted and communicated to teachers to inform differentiated instruction focused on CT skills.

2. CURRENT PROJECT PURPOSE
This study is part of a larger interdisciplinary project designed to develop a game-based learning environment within the existing Minecraft mod "Lumber Jack Tycoon." The learning environment will be developed for middle grades students, designed around focus CSTA computer science standards with an emphasis on CT. Teachers will receive information about their students' progress toward mastering learning standards through integration between the game, a data collection cloud infrastructure, and a learning management system called Canvas.

We use design-based implementation research (DBIR) to guide the development of the game-based learning environment (Confrey, 2019; Fishman, et al., 2007; Penuel et al., 2011). As such, we rely heavily on co-development with educators who work directly with students who the game will ultimately serve. We formed an Educator Advisory Panel (EAP), which included middle grades educators with an interest in computer science and CT. The five EAP educators represented six middle schools across four public school districts in the southern United States. Three educators identified as teachers, one identified as an instructional coach, and one identified as an instructional technology specialist.

Working with five EAP members, we identified middle grades CSTA computer science standards to focus on within the game (subsequently referred to as the focus standards). These standards were: (a) high priority for teachers' instruction, (b) tended to be difficult to teach, (c) may be taught efficiently in Minecraft, and (d) were relevant to CT (Tseng et al., 2020). The selected standards were grouped thematically into four groups including: (a) data and analysis, (b) problem decomposition, (c) teamwork and organization, and (d) equity and impact. For the purpose of this paper, we target the focus standards for data and analysis. We selected this group of standards given the strong connections to STEM disciplines and CT.

As part of the larger project, we developed a process for decomposing the game and standards separately and then integrating those decompositions to create the game-based learning environment. For the purpose of this study, we describe the standard decomposition process that was developed to unpack or decompose content standards into components that illustrate CT skills. We refer to this process as the standard decomposition process throughout this paper. Our research question is: Using the standard decomposition process and incorporating educator feedback, what are the evidences of learning and mastery for three middle grades CSTA focus standards relating to the data and analysis thematic group (2-DA-07, 2-DA-08, and 2-DA-09)?

3. METHOD

Guided by DBIR, we partnered with educators to decompose the three focus standards. A primary goal of this work was to create standard decomposition tables that could be used to inform assessment development within the game-based learning environment. The standard decomposition process included seven phases, which began in August 2020 and are ongoing. In this section, we describe the seven phases (3.1 - 3.7) that comprise the standard decomposition process.

3.1 Identify Existing Curricula Related to the Focus Standards

We developed a repository of curricular resources related to middle grades computer science and CT. These curricular resources were identified through a web search, as well in consultation with our EAP and other researchers engaged in this work. These resources included well-developed data and analysis units with learning activities that were focused on conceptual understanding, rather than programming or coding.

3.2 Review Curricular Resources.

Two researchers separately reviewed the curricular resources to decompose each standard into:

1. **Steps** related to each standard, suggesting an order for the cognitive processes that students might engage in related to the overall standard
2. The **importance or objectives (OI)** for each step within the standard decomposition
3. The **pre-knowledge, skills, and abilities (pre-KSAs)** that students would need to develop as evidence of learning or evidence that they are progressing toward mastery within each step of the standard decomposition (e.g., necessary pre-requisite knowledge related to each standard)
4. The **knowledge, skills, and abilities (KSAs)** that students would need to develop as evidence of mastery within each step of the standard decomposition

3.3 Reconcile Differences.

Researchers met to collaboratively discuss standard decomposition tables and combine their separate tables into one standard decomposition table including steps related to each standard, each with corresponding OIs, pre-KSAs, and KSAs.

3.4 Gather Educator Feedback on the Steps, OIs, Pre-KSAs, and KSAs.

We met virtually with five EAP members to discuss the focus standards and the extent to which the steps, OIs, pre-KSAs, and KSAs reflected their expectation of what their students should know and be able to perform related to the focus standard. For 2-DA-08, we drafted example **evidence of learning (EoL)** corresponding to the pre-KSAs and **evidences of mastery (EoM)** corresponding to the KSAs, which reflected observable behaviors that students demonstrate in the classroom related to each standard. During the meeting we also encouraged the five educators to provide EoL and EoM related to 2-DA-07 and 2-DA-09. Following the meeting, we solicited additional feedback on the standard decomposition tables using Google Documents. Two of five educators participated in the additional opportunity to provide feedback.

3.5 Integrate Feedback from Educators and Generate EoL and EoM based on Existing Curricula and Educator Feedback

Following the virtual meeting with educators, we systematically reviewed the meeting transcript and researcher notes to refine the content of the standard decomposition tables based on educator feedback. In addition, we generated EoL and EoM for 2-DA-07 and 2-DA-09 based on educator feedback and the review of curricular resources.

3.6 Confer with Educators and Gather Educator Feedback on the EoL and EoM.

We invited educators to provide feedback asynchronously on the complete standard decomposition tables using an online platform called Google Jamboard. One of the purposes of this review was to ensure that we accurately captured educator feedback in our revisions. A second purpose was for educators to provide feedback on the EoL and EoM for 2-DA-07 and 2-DA-09. Two of five educators participated in this opportunity.

3.7 Integrate Feedback from Educators.

We systematically reviewed the educator comments related to the updated standard decomposition tables and refined the language in the standard decomposition tables based on educators' feedback.

4. RESULTS

In this section, we summarize the EoLs and EoMs for the focus standards and summarize changes that we made based on educators' feedback. These tables directly relate to this study's research question, which focuses on identifying EoL and EoM. Tables 1 through 3 include sample EoL and EoM statements from the full standard decomposition tables. The contents of these tables identify a sample of behaviors that students demonstrate to show EoL or EoM with an emphasis on CT related to the focus standards, informed by a review of existing curricula and feedback from five educators.

Table 1 includes a sample of EoL and EoM for 2-DA-07: Represent Data using Multiple Encoding Schemes. We identified three steps within this standard including (1) access data, (2) clean data, and (3) create and apply encoding rules.

Table 2 includes a sample of the EoL and EoM for 2-DA-08: Collect Data using Computational Tools and Transform the Data to Make it More Useful and Reliable. We identified four steps within this standard including (1) collect data, (2) clean data, (3) organize data, and (4) explain data.

Table 3 includes a sample of EoL and EoM for 2-DA-09: Refine Computational Models based on the Data [Students] have Generated. We identified two steps within this standard including (1) review model output, and (2) refine the model.

Table 1. Sample of Standard Decomposition Table for "2-DA-07: Represent Data using Multiple Encoding Schemes".

Steps	EoL	EoM
Access Data	Manipulate data using computing devices to aid human processing	Identify the type of data (e.g., numeric, categorical) Explain why different types of data are valuable
Clean Data	Filter variables to identify which data are necessary	Recognize patterns within a column or row of data
Create and Apply Encoding Rules	List possible encoding methods Describe the necessary features of an encoding system Choose the best way to encode information based on how it will be used	Evaluate different encoding methods used Compare encoding methods with other students' work Resolve conflicts when using encoding rules

Table 2. Sample of Standard Decomposition for "2-DA-08: Collect Data using Computational Tools and Transform the Data to Make it More Useful and Reliable".

Steps	EoL	EoM
Collect Data	Identify examples of data and non-data	Identify and record relevant data
Clean Data	Make decisions about how to handle missing data	Compare cleaning strategies with other students
Organize Data	Identify different systems for representing data	Employ an effective data organization system with team members
Explain Data	Evaluate different organizational systems	Explain how data were identified, collected, and stored in a way that connects to solving a problem

Table 3. Sample of Standard Decomposition Table for "2-DA-09: Refine Computational Models based on the Data [Students] have Generated".

Steps	EoL	EoM
Review Model Output	Extend encoding schemes to rules of models	Describe how data generated by the model help solve a problem
Refine the Model	Identify opportunities to improve the model	Create an improved model (i.e., more accurate, efficient, simpler, and/or intuitive)

The sample content from Tables 1 through 3 reflects the types of behaviors that students would be expected to display in the classroom related to each of the focus standards, with an emphasis on CT skills.

Because this study's research question specifies the incorporation of five educators' feedback across iterations of the EoL and EoM, we share general findings related to how the standard decomposition tables evolved based on educator feedback. In the initial synchronous feedback session, the educators registered concern about students' lack of familiarity with computers. Further, the educators emphasized the need for scaffolding. Based on educator comments on specific statements, we made a number of revisions and additions. Following the first feedback session, the number of statements for 2-DA-08 increased two-fold and many of the previous statements were clarified based on educator feedback. Time constraints meant only eight suggestions were received on 2-DA-07 and none on 2-DA-09. During the follow up asynchronous feedback opportunity, two educators identified having students do things multiple ways, the use of peers for sharing and review, and the use of manipulatives as positives. Although there was a similar number of changes suggested on specific items in the second round of feedback, most of the comments were on clarifying the language of the standards and making the verbs as observable as possible.

5. DISCUSSION

This paper describes a standard decomposition process designed to inform the development of an online game-based learning environment in Minecraft. The process described in this paper explicates student behaviors that build from progressing toward mastery (i.e., EoL) to mastery (i.e., EoM). As such, the types of behaviors or cognitive processes that students are expected to do are articulated. The standard decomposition process defined student behaviors connected to the standards that emphasize CT skills. This information subsequently informs what students will actually be expected to do within the gaming experience.

The standard decomposition tables are a contribution to the field of education focused on computer science and CT because they build on existing assessment work in CT (Grover et al., 2015; Grover et al., 2017). The standard decomposition tables were co-developed with five educators within a DBIR framework. The phases described in the methods of this paper outline a process for gathering and integrating educator feedback systematically. Due to space limitations, this paper includes a sample of the standard decomposition tables.

Minecraft allows us to build a community-based gaming environment that facilitates an understanding of CT. Our next step is to integrate the learning standard decompositions with the game element decompositions. This integrative step will result in the development of learning experiences within Minecraft. This game development process is highly scalable for others interested in doing similar game development work.

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