Studying computational thinking in K-12 education through learning analytics: towards a systematic mapping protocol

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ABSTRACT

The ever-increasing interest of the research community around students' Computational Thinking (CT), as well as the vast number of related studies that have been produced until today, calls for systematic efforts to summarize the knowledge in the field. This work explores the adaptation of general guidelines for conducting rigorous reviews to the distinct needs of a systematic mapping focusing on studies that assess CT in K-12 education through Learning Analytics (LA). Well-known guidelines for systematic mapping studies were used as the methodological framework and topic-specific issues penetrating CT and LA were explored in order to formulate a topic-informed protocol. Making this protocol publicly available will strengthen the transparency and rigorousness of the systematic mapping in the field of learning technologies.

KEYWORDS

Computational thinking, learning analytics, systematic mapping, K-12, education

RÉSUMÉ

L'intérêt toujours croissant de la communauté de recherche autour de la pensée computationnelle (PC) des étudiants, ainsi que la grande quantité d'études connexes, produites jusqu'à aujourd'hui, appellent à des efforts systématiques pour rassembler les connaissances en la matiere. Ce travail explore l'adaptation des directives générales pour la conduite des revisions rigoureuses aux besoins distincts d'une cartographie systématique en se concentrant sur les études qui évaluent le PC dans l' education K-12 via Learning Analytics (LA). Des directives bien connues pour les études cartographiques systématiques ont été utilisées comme cadre méthodologique et les problèmes spécifiques au sujet pénétrant la PC et les LA ont été explorés afin de formuler un protocole basé sur le sujet. Rendre ce *protocole accessible au public renforcera la transparence et la rigueur de la cartographie systématique dans le domaine des technologies d'apprentissage.*

MOTS-CLÉS
Pensée Computationelle, Learning Analytics, cartographie systématique, Education, K-12

INTRODUCTION

From the publication of Jeannette Wing’s influential work about Computational Thinking (CT) in 2006 until now, a vast number of studies that investigate and assess CT in children of all ages has been published. Thus, there arises the need for systematic efforts to record and summarize the knowledge and activity produced all these years in the field. To this end, systematic mapping is the appropriate method for structuring and organizing a research area in breadth (Petersen, Vakkalanka, & Kuzniarz, 2015).

Systematic mapping seeks to answer broader research questions and provide an overview of a research area, by sorting studies into a classification scheme and presenting the frequencies of contributions for each category (Petersen, Feldt, Mujtaba, & Mattsson, 2008). However, systematic mapping studies follow the same rigorous, objective and transparent processes as systematic reviews do and, hence, they avoid the risks of traditional literature reviews, like reviewer and publication bias (James, Randall, & Haddaway, 2016). For this reason, before the study is started, it is crucial to formulate a research protocol which will describe the planned methods and will serve as a guide for decision-making while carrying out the systematic mapping.

Existing guidelines for conducting secondary research help researchers define their review protocols. However, although these comprehensive guidelines introduce the methodology for performing rigorous reviews, they provide a relatively high-level description, since they do not consider the impact of the research topic on the review procedures. Therefore, researchers need to inform these generally applicable procedures with topic-specific knowledge in order to develop review protocols that appropriately address the distinct needs of their problem under study.

In view of conducting a systematic mapping of studies that assess CT in K-12 education through Learning Analytics (LA), the first step is to formulate the review protocol. The purpose of this work is to investigate how core concepts of the research topic (namely, the CT construct and LA methods) inform the procedures typically included in a systematic mapping protocol.

METHODOLOGICAL FRAMEWORK

Exploring topic-specific issues

How is CT conceptualized?

CT “*represents a universally applicable attitude and skill set everyone, not just computer scientists, would be eager to learn and use*” (Wing, 2006). Although programming interventions can help foster children’s CT (Lye & Koh, 2014), CT is not solely connected with coding. CT skills are necessary in order to properly program; yet, students can develop and apply their CT skills in other contexts that are disconnected from computer programming (Román-González, Moreno-León, & Robles, 2019). Thus, defining the intervention for assessing CT (e.g., programming, unplugged activities) is an important point of consideration when developing a review protocol. Additionally, since CT is a multi-dimensional construct which researchers have described through different constituent variables, it is essential to adopt a theoretical framework that will consolidate the idea of "*assessing CT*". However, it should be noted that not all theoretical frameworks are suited for every review on CT, since the type of intervention and target population may affect their applicability. Lye and Koh (2014) propose the theoretical framework by Brennan and Resnick (2012) as a well-suited framework for reviewing CT through programming interventions in K-12 education. It is a well-established framework that features three dimensions of CT (computational concepts, practices and perspectives), which emerged from studies engaging children in programming activities in Scratch and can be transferred to other programming environments for K-12 students, as well.

What do LA offer in CT assessment?

Research tools for assessing CT can be mainly divided into tools measuring the CT aptitudinal level, tools assessing learning outcomes after instruction, tools assessing students' programming products and LA tools that record students' programming activity in real time (Román-González et al., 2019). In contrast to the other types of tools, which assess the *outcome* of students' thinking (be it a response to a questionnaire item or the source code of their final programming solution), LA tools capture students' thinking *process*, moving the study of CT from static to dynamic. This offers the opportunity to better examine CT practices and perspectives, which are often overlooked (Lye & Koh, 2014). When developing the review protocol, it should be taken into consideration that there are two fields that researchers refer to, when employing this data-driven approach for assessing CT: LA and Educational Data Mining (EDM). Although EDM focuses more on techniques and methodologies and LA deals more with applications, their differences are less and less noticeable and the two terms are treated as interchangeable (Liñán & Pérez, 2015). LA and EDM share common computational methods (such as process mining, clustering, discovery with models), powered by statistical and machine-learning techniques, in order to analyze student programming behavior and uncover patterns (Liñán & Pérez, 2015). In the review protocol, these methods can inform keywords in the search string.

Formulating the systematic mapping protocol

The development of the following protocol was based on the guidelines for systematic mapping studies by Petersen, Vakkalanka and Kuzniarz (2015). These guidelines served as the methodological framework, into which the topic-specific knowledge from the previous subsection was integrated, in order to formulate a topic-informed protocol.

Purpose of the systematic mapping study

The purpose of the systematic mapping study is to provide an overview of the use of LA for assessing K-12 students' CT while engaging in programming activities.

Research questions

The formulation of the research questions (RQs) was based on the PICOC framework (Population, Intervention, Comparison, Outcomes, Context), as described in Table 1.

The systematic mapping study includes four RQs:

- RQ1) What is the student population of the studies?
- RQ2) What are the features of the programming activities for studying CT?
- RQ3) How is students' programming activity recorded and analyzed through LA?
- RQ4) What CT trajectories are suggested in the research?

TABLE 1

Analysis of the problem under consideration based on the PICOC framework

ID	Criterion	Description
C1	Population	K-12 students
C2	Intervention	Programming activities
C3	Comparison	LA/EDM methods and techniques
C4	Outcomes	Computational Thinking (concepts, practices, perspectives)
C5	Context	Formal, non-formal and informal education

Literature search

Searches will be run on four databases, namely ERIC, IEEE Xplore, Scopus and Web of Science. Additionally, manual searching will be performed in reference lists. The search string will combine keywords with the Boolean operators OR and AND, as follows: ("computational thinking" OR "computational concept" OR "computational practice" OR "computational perspective" OR "programming task" OR "programming activity" OR "programming problem" OR "programming concept" OR "programming practice" OR "programming perspective" OR "programming pattern" OR "programming process" OR "programming trajectory" OR "programming behavior" OR "programming profile" OR "programming actions" OR "programming solution" OR "programming assessment") AND (analytics OR "data mining" OR "data-driven" OR logs OR "machine learning" OR clustering OR prediction OR modeling OR "process mining" OR "relationship mining" OR "pattern mining" OR "rule mining") AND (education OR students OR children OR learners OR preschool OR kindergarten OR elementary OR primary OR "middle school" OR "high school" OR "secondary school"). The keywords were refined by iteratively trying to find more relevant papers. Search will be conducted against the title, abstract, keywords and descriptor (in ERIC) of the articles. In order to evaluate the identification strategy, a test-set of carefully selected papers (which fall within the scope of the study) will be created so as to determine how many of them are included or missed from the list.

Inclusion and exclusion criteria

The systematic mapping will include/exclude studies based on the criteria presented in Table 2.

TABLE 2

The inclusion and exclusion criteria of the study

Inclusion criteria	Exclusion criteria
Studies investigating CT concepts, practices and perspectives through programming activities in K-12 students	Studies not presenting an analytical methodology that details the CT concepts, practices and perspectives under consideration as well as how they are captured and analyzed (e.g., types of logging data).
Studies that implement LA and EDM techniques for capturing and analyzing students' programming activity	Studies that explore CT in participants other than K-12 students or studies that do not define the participants. Studies not defining the participants, yet implementing programming environments designed for K-12 students (e.g., Scratch), will be accepted and included.
Studies written in English	Studies whose full-text is not available.
	Multiple publications of the same study. In order to avoid over-representation bias, only the most complete version will be included.

Procedure

The systematic mapping process will follow the three main steps (identification, screening, eligibility) suggested in PRISMA (Moher et al., 2009). In the eligibility phase, two researchers will independently assess the full-texts and inter-rater reliability will be measured. In case of disagreements, a third reviewer will independently assess the studies, in order to reach a final decision. Studies considered eligible will be included in the systematic mapping research. Indicative examples of eligible studies to be included in the review are: Eguiluz et al. (2017), Grover et al. (2017) and Filvà et al. (2019).

Data extraction

Data extraction for each research question is presented in Table 3. A data extraction spreadsheet will be created. Classification schemes will be of two kinds: topic-independent (e.g., publication venues) and topic-specific schemes. Topic-specific classification will be performed through thematic analysis, using existing schemes (e.g., CT framework by Brennan & Resnick, 2012) or themes emerging from the data. A second researcher will check data extraction and will assess data coding and coding categories in terms of internal homogeneity and external heterogeneity, as suggested for reviewing themes in thematic analysis (Braun & Clarke, 2006).

TABLE 3

Data extraction for each research question

Research Question	**Data**
(General information)	Title of the study, author(s), publication year, publication venue (e.g., scientific conference, journal)
RQ1	Education level (preschool, primary, secondary), student age, number of students
RQ2	Programming environment, type of programming activity (closed or open-ended), number and duration of the programming activities, CT concepts or practices or perspectives under investigation
RQ3	Types of logging data (e.g., clickstreams, sequence of programming commands), variables created (e.g., code length, code revisions), method of analysis (e.g., clustering), additional CT metrics and assessments (e.g., questionnaires)
RQ4	The goals of the programming activities regarding CT and their progression levels, research outcomes suggesting such progression levels

Quality assessment

The systematic mapping study does not intend to assess the effectiveness of an educational intervention, like systematic reviews typically do, but to describe studies that assess CT through LA and provide an overview of the field. Thus, in systematic mapping no quality assessment needs to be performed, since even studies with no empirical evidence may be considered important for spotting trends of ongoing research (Petersen et al., 2015). Nevertheless, in case that synthesis of empirical evidence is needed, quality assessment will be conducted.

CONCLUDING REMARKS

This work explored the adaptation of general guidelines for conducting rigorous reviews to the distinct needs of a systematic mapping focusing on studies that assess CT in K-12 children through LA. The guidelines for systematic mapping studies by Petersen et al. (2015) were used as the methodological framework and topic-specific issues penetrating CT and LA were explored in order to formulate a topic-informed protocol.

Publishing the research protocol is strongly advised when conducting secondary research that intends to be rigorous and transparent, like systematic reviews and systematic mapping studies. Another contribution of making this systematic mapping protocol publicly available is its reusability. One of the advantages of systematic mapping studies is the fact that the research protocols can be reused, helping researchers to extent research in the field, by easily adapting research procedures to new studies, whilst saving time (Kitchenham, Budgen, & Brereton, 2010). This applies especially to the present work, which did not just present a review protocol but highlighted the rationale for integrating topic-specific knowledge into generally applicable review procedures.

Nevertheless, developing a systematic mapping protocol is an iterative process, which necessitates piloting the protocol in order to detect mistakes, needs and weaknesses (Brereton et al., 2007). Therefore, the protocol explored in this work is a preliminary effort, which will be evaluated by piloting all stages described (from literature searching to data extraction and implementation of classification schemes) and will be revised accordingly.

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