DCEP-SE: A Dublin Core Application Profile for Experimental Software Engineering

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Abstract. *Experimental Software Engineering (ESE) faces persistent challenges in the standardization of metadata for artifacts, which limits the replication, comparison, and reuse of experimental results. Metadata provides a structured means to describe artifacts, thereby enhancing reproducibility; however, widely adopted standards such as Dublin Core (DC) may not adequately capture the specific requirements of ESE. To address this gap, this study proposes and validates* ***DCEP-SE****, a DC-based application profile tailored for documenting software engineering experiments. The profile was iteratively refined through the progressive exclusion of non-essential elements, resulting in a concise set of qualified terms aligned with experimental phases. DCEP-SE was applied to a real-world study, enabling systematic documentation of context, variables, and results. The profile enhances interoperability, promotes artifact reuse, and standardizes the reporting of ESE studies. Moreover, it provides a reusable methodological process for developing domain-specific metadata profiles in experimental software engineering.*

1. Introduction

Experimental Software Engineering (ESE) employs empirical methods, such as controlled experiments, to evaluate the methods, tools, and processes proposed within the field of Software Engineering [Wohlin et al. 2024]. The execution of these experiments generates a variety of artifacts, including source code, images, documentation, raw data, models, and specifications, particularly data and metadata [Abou Khalil and Zacchiroli 2022, IEEE Standards Association 2017]. However, the absence of standardization in their management compromises essential scientific principles such as repetition, replication, and reproduction. It also limits the comparison of results and the reuse of data [Méndez Fernández et al. 2019, Timperley et al. 2021]. Beyond artifacts, inconsistencies in the description of experimental data have also been reported [Madeyski et al. 2017, Fucci 2024].

In digital environments, metadata and metadata standards play a crucial role in uniquely describing informational resources. They enable multiple forms of access and use, facilitate retrieval, and support interoperability [Formenton and Gracioso 2022]. The literature reports a wide range of metadata standards [Santana et al. 2023b], among which Dublin Core (DC) stands out for its simplicity and flexibility [Santana et al. 2023a]. DC defines a basic set of 15 elements that can be used to describe a broad spectrum of informational resources [DCMI Usage Board 2020].

An *application profile*, in turn, specifies how metadata terms are adapted and applied in a particular context [Dublin Core™ 2005]. Examples include the Dublin Core Application Profile (DCAP) [Curado Malta and Baptista 2013], AGRIS [FAO 2005], the Mountain West Digital Library profile [Walters 2010], the Scholarly Works Application Profile (SWAP), and DataCite [DataCite 2024].

This work aims to improve the description of datasets generated or reused in the context of ESE, reduce difficulties in understanding metadata files, facilitate experimental activities such as repetition, replication, and reproduction, enhance the management of experimental metadata, and provide better conditions for the reuse of data by other tools and projects.

To achieve these goals, the study presents the Dublin Core Experimentation Profile for Software Engineering (**DCEP-SE**) and the specification of a systematic process for developing metadata profiles applicable in any domain, providing a methodological foundation for consistent, interpretable, and reusable documentation of experimental data.

The remainder of this paper is organized as follows: Section 2 reviews existing metadata application profiles; Section 3 presents the study objectives, literature review, and methodology for designing DCEP-SE; Section 4 details the results; Section 5 discusses results; and Section 6 discusses conclusions and future directions.

2. Background

An application profile integrates selected terms from multiple vocabularies, including constraints, to meet the needs of a specific application [Miksa et al. 2021]. They have been developed for scientific and scholarly contexts, such as the Scholarly Works Application Profile (SWAP) and DataCite [Allinson et al. 2006, DataCite 2024]. Other examples include AGRIS, developed for agricultural information systems, and the Mountain West Digital Library application profile [FAO 2005, Walters 2010].

An application profile describes, explains, and defines additional rules for how existing vocabularies and models should be used in a metadata instance [Coyle et al. 2023]. Standards provide the foundation for creating application profiles [Curado Malta 2012]. Application profiles are composed of data elements drawn from one or more namespaces, combined and optimized for specific local applications [Heery and Patel 2000].

In the context of metadata standardization, the Dublin Core Metadata Initiative (DCMI) defined a methodology to support the development of application profiles, known as the Dublin Core Application Profile (DCAP) [Dublin Core™ 2005]. A DCAP specifies the objectives to be achieved with its application through functional requirements, characterizes the described entities and their relationships by means of a domain model, enumerates the metadata terms and usage rules in the form of description set profiles and usage guidelines, and establishes the encoding syntax through syntax guidelines and data formats [Nilsson et al. 2008].

3. Methodology

This section describes the methodology applied in this study. This methodology was structured based on the definition of objectives, a non-systematic literature review, and the development of the application profile.

3.1. Objectives

This study has two objectives: to investigate and evaluate existing DC-based metadata schemas and application profiles reported in the literature, and to specify a reusable process for the development of a domain-specific metadata profile.

3.2. Literature Review

A non-systematic literature review was conducted on **October 16, 2024** using **Google Search** to identify DC-based metadata schemas and application profiles. The search combined terms such as "**Dublin Core metadata schemas**", "**Dublin Core metadata profile**", and "**metadata profiles**", returning 29 application profiles and 12 metadata schemas. Metadata schemas were discarded. Application profiles are defined as specifications that select terms from multiple schemas and add constraints to meet the requirements of a specific application or context [Miksa et al. 2021, Curado Malta and Baptista 2013]. In contrast, a metadata schema is an organized set of elements standardizing the semantic and syntactic description of metadata instances [Nagamori and Sugimoto 2007].

Metadata schemas were excluded because their structures were insufficient for adequately documenting SE experiments. In the literature search, results retrieved under the term "**metadata schema**" proved to be essentially equivalent to "**metadata standard**", reflecting the rigid structure of existing metadata standards. For instance, Archivematica employs the DC "as is", embedding it directly into METS `<dmdSec>` sections without any domain-specific extensions, thereby producing metadata records that are not detailed enough for certain specialized contexts [Archivematica 2019]. Therefore, developing an application profile with application-specific elements became necessary to ensure clarity, consistency, and completeness in metadata registration. Three application profiles were selected for detailed analysis: AGRIS [FAO 2005], the Mountain West Digital Library DC Application Profile [Walters 2010], and DataCite[DataCite 2024].

The **AGRIS Application Profile**, developed by the Food and Agriculture Organization (FAO), standardizes the exchange of agricultural information across AGRIS centers. It combines DC with the Agricultural Metadata Element Set (**AgMES**), a metadata scheme with agriculture-specific refinements and controlled vocabularies such as AGROVOC, to enhance description, discovery, and interoperability [FAO 2005, AgMES 2010].

The **Mountain West Digital Library DC Application Profile** was created by the Utah Academic Library Consortium to support digital collections across multiple institutions. It integrates DC with practical guidelines for interoperability and consistency, emphasizing alignment with other metadata standards used in libraries and digital repositories [Walters 2010].

The **DataCite** is widely adopted for the registration and citation of research data. It extends DC principles with detailed elements for persistent identification, creators, contributors, funding references, and resource types, making it highly influential in data management and scholarly communication [DataCite 2024].

The AGRIS profile was selected as the most suitable reference due to the rigor and clarity of its documentation. Its guidelines not only present the profile itself but also provide a systematic, step-by-step account of the construction process and how the elements were derived and organized.

Beyond its documentation, the AGRIS profile is specifically designed to enhance the description, exchange, and retrieval of Document-Like Information Objects in the agricultural domain. It incorporates elements from standards such as DC, the Australian Government Locator Service Metadata (AGLS) [National Archives of Australia 2023], and AgMES [AgMES 2010] to facilitate information sharing between bibliographic systems and provide guidelines for cataloging and indexing.

3.3. Application Profile

The development of the DCEP-SE profile began with an analysis of a reference profile to examine its structure, documentation, and mandatory elements. Experimental stages defined by Wohlin [Wohlin et al. 2024] were initially mapped to all 15 DC elements, creating a broad first version of the profile.

This initial version proved excessive, as not all elements were relevant for each experimental phase, as shown in Figure 1a. In a second version, elements representing the experimental stages themselves were introduced, and DC elements were applied in sequence. A template based on Wohlin's experimental workflow was elaborated to align the experimental steps with potential qualifiers.

To refine the profile, a third version adopted `dc:description` to represent experiments, mapping each stage of Wohlin's process to specific DC elements in a streamlined manner. The study by Porter et al. [Porter et al. 1995] was used to populate the elements, and they were removed progressively until any further reduction would compromise the coherence of the description. This process identified the minimal set of elements necessary for each phase, avoiding redundancy.

The final version incorporated small refinements to improve clarity and completeness, adding elements to reference the research team and retaining only the minimal set necessary to describe each stage.

The final version, illustrated in Figure 1b, maps experimental sub-steps to selected DC elements, with each sub-phase treated as a qualifier containing only the necessary metadata.

4. Results

The results of this study consist of the definition of a domain-specific application profile for ESE. This profile, called DCEP-SE, was designed to register metadata from experiments in the SE domain. The resulting profile offers a structured approach to describing various aspects of experimental studies. Another contribution was the development of a reproducible process for creating metadata profiles. The steps for the construction of metadata application profiles are presented below.

1. Consult the reference standard or profile to analyze its structure, documentation, mandatory elements, terms, and other normative aspects that guide the modeling of the new profile.
2. List the technical definitions from the reference standard, identifying the elements relevant to the context of application.
3. Create a preliminary model to organize the selected elements and possible qualifiers that will form the basis of the profile structure.

```xml
<experiment_phase>
    <dc:title></dc:title>
    <dc:creator></dc:creator>
    <dc:subject></dc:subject>
    <dc:description></dc:description>
    <dc:publisher></dc:publisher>
    <dc:contributor></dc:contributor>
    <dc:date></dc:date>
    <dc:type></dc:type>
    <dc:format></dc:format>
    <dc:identifier></dc:identifier>
    <dc:source></dc:source>
    <dc:language></dc:language>
    <dc:relation></dc:relation>
    <dc:coverage></dc:coverage>
    <dc:rights></dc:rights>
</experiment_phase>
```

(a) DCEP-SE Version 1.0, associating all DC elements to each experimental phase [Wohlin et al. 2024].

```xml
<resource.experiment>
    <dc:subject.team>
        <dc:title></dc:title>
        <dc:creator></dc:creator>
        <dc:contributor></dc:contributor>
        <dc:date></dc:date>
    </dc:subject.team>

    <dc:subject.scope>
        <dc:description.definition></dc:description.definition>
    </dc:subject.scope>

    <dc:subject.planning>
        <dc:description.context></dc:description.context>
        <dc:description.hypothesis></dc:description.hypothesis>
        <dc:description.variables></dc:description.variables>
        <dc:description.sample></dc:description.sample>
        <dc:description.experiment.design></dc:description.experiment.design>
        <dc:description.instrumentation></dc:description.instrumentation>
        <dc:description.validity.evaluation></dc:description.validity.evaluation>
    </dc:subject.planning>

    <dc:subject.operation>
        <dc:description.preparation></dc:description.preparation>
        <dc:description.execution></dc:description.execution>
        <dc:description.data.validation></dc:description.data.validation>
        <dc:description.coverage></dc:description.coverage>
    </dc:subject.operation>

    <dc:subject.analysis>
        <dc:description.descriptive.statistics></dc:description.descriptive.statistics>
        <dc:description.data.set.reduction></dc:description.data.set.reduction>
        <dc:description.hypothesis.testing></dc:description.hypothesis.testing>
    </dc:subject.analysis>

    <dc:subject.presentation>
        <dc:description.report></dc:description.report>
        <dc:description.package></dc:description.package>
        <dc:description.identifier></dc:description.identifier>
        <dc:description.format></dc:description.format>
        <dc:description.language></dc:description.language>
        <dc:description.source></dc:description.source>
        <dc:description.rights></dc:description.rights>
    </dc:subject.presentation>
</resource.experiment>
```

(b) Final DCEP-SE profile Dublin Core elements [Wohlin et al. 2024, Porter et al. 1995].

Figure 1. Comparison between initial and final versions of the DCEP-SE profile.

4. Populate the profile elements with all standard metadata elements according to the experimental stages. Then, iteratively remove non-essential or redundant elements until a minimal, coherent set is obtained, containing only those elements necessary to clearly describe the specific metadata profile element being refined.
5. Develop a formal version of the profile, specifying the elements and qualifiers in accordance with the reference standard for general descriptions.
6. Apply adjustments to ensure coherence, consistency, and applicability of the profile.
7. Produce a specification table consolidating all defined elements and their usage rules, enabling practical application, reproducibility, and interoperability.

Figure 2 presents the complete set of metadata elements defined in the DCEP-SE profile. The elements originate from the DC standard, with some directly adopted and others refined as qualifiers corresponding to specific experimental sub-phases. The `subject.*` elements provide general information about the experimental aspects, such as the research team (`subject.team`) or the planning and execution stages (`subject.planning`, `subject.operation`). In contrast, the `description.*` elements provide a deeper, more detailed account of the experiment, including context, hypotheses, variables, instrumentation, and results. Each DC element defines the high-level category, and the qualifier specifies the level of detail required for documenting a particular stage of the experiment. The dash (–) in the specification column indicates that the DC element is used in its original form without additional refinement.

To demonstrate the applicability of the DCEP-SE profile, the experiment *Comparing Detection Methods for Software Requirements Inspections* [Porter et al. 1995] was

Element	Element Specification	Rules
(DC) title	-	The title must be associated with the research problem that motivated the experiment.
(DC) creator	-	The names of the research team members must be listed.
(DC) contributor	-	The names of other researchers outside the team who contributed to the experiment must be listed.
(DC) date	-	The date of the experiment must be recorded.
(DC) subject	subject.team	General information about the team and the experiment
	subject.scope	Subject of the study or experiment objectives
	subject.planning	Subject related to experiment planning
	subject.operation	Subject related to experiment execution
	subject.analysis	Subject concerning the processing and analysis of collected data
	subject.presentation	Results and conclusions obtained from the experiment as a package
(DC) description	description.definition	The scope of the experiment must be defined.
	description.context	The context adopted in the experiment must be described.
	description.hypothesis	The hypotheses considered in the experiment must be described.
	description.variables	The variables considered in the experiment must be described.
	description.sample	The sample used in the experiment must be specified.
	description.experiment.design	The experimental design adopted in the experiment must be described.
	description.instrumentation	The artifacts used in planning and executing the experiment must be specified.
	description.validity.evaluation	The threats to validity observed in the experiment must be described.
	description.preparation	The preparation procedures for executing the experiment must be described.
	description.execution	The procedures for executing the experiment must be described.
	description.data.validation	The procedures for validating the data collected in the experiment must be described.
	description.descriptive.statistics	The descriptive statistics measures used in the data analysis must be specified.
	description.data.set.reduction	The actions taken to reduce the data set must be described.
	description.hypothesis.testing	The hypothesis tests considered during the analysis must be specified.
	description.report	Information about the document presenting the experiment results must be provided.
	description.package	Information about the experimental package must be provided.
	description.rights	A person or organization that owns or manages the rights to the resource.
	description.coverage	The geographic coverage of the experiment must be specified.
	description.identifier	The identifier associated with the experiment, such as a DOI, must be provided.
	description.format	The format of the experimental package must be specified.
	description.language	The language of the experimental package must be specified.
	description.source	A related resource from which the described resource is derived. The described resource may be derived from the related resource entirely or partially.

Figure 2. Metadata element specification and rules of the DCEP-SE profile

mapped. Figures 3a and 3b illustrate excerpts of this representation, showing how the metadata elements can be populated to provide a structured and reusable description of the experiment.

We understand that this example allowed for a structured and detailed description of the experiment, capturing general information, context, hypotheses, variables, sample, design, preparation, execution, data validation, analysis, and dissemination aspects. Through this representation, we believe that the profile contributed to a clearer description of the datasets generated and reused, reduced potential difficulties in understanding the metadata, and facilitated activities such as repetition, replication, and reproduction. It also provided conditions to improve the management of experimental metadata and the reuse of this data.

```xml
<resource.experiment>
    <dc:subject.team>
        <dc:title>Comparing Detection Methods for Software Requirements Inspections</dc:title>
        <dc:creator>
            Adam A. Porter; Lawrence G. Votta, Jr.; Victor R. Basili; Mark Ardis;
            John Kelly; David Weiss; John Gannon; Richard Gerber; Clive Loader;
            Eric Slud; Scott VanderWeil
        </dc:creator>
        <dc:contributor>Experimental participants</dc:contributor>
        <dc:date>1995-06-01</dc:date>
    </dc:subject.team>

    <dc:subject.scope>
        <dc:description.definition>
            Evaluation of fault detection methods Ad Hoc, Checklist,
            and Scenario for software requirements inspections using replicated controlled
            experiments.
        </dc:description.definition>
    </dc:subject.scope>

    <dc:subject.planning>
        <dc:description.context>
            Academic setting with graduate students as reviewers.
        </dc:description.context>
        <dc:description.hypothesis>
            Scenario-based method yields higher fault detection rates
            than Ad Hoc or Checklist methods.
        </dc:description.hypothesis>
        <dc:description.variables>
            Independent variables: Detection method, Replication, Inspection round, Specification order.
            Dependent variables: Individual fault detection rate, Team fault detection rate, Meeting gain/loss rate.
        </dc:description.variables>
        <dc:description.sample>
            48 graduate CS students, organized into sixteen 3-person teams.
        </dc:description.sample>
        <dc:description.experiment.design>
            3x2 partial factorial randomized design with two replications.
        </dc:description.experiment.design>
        <dc:description.instrumentation>
            Software Requirements Specifications (WLMS, CRUISE), fault taxonomy, checklists,
            scenario procedures, fault report forms.</dc:description.instrumentation>
        <dc:description.validity.evaluation>
            Internal threats: Selection, Maturation, Replication, Instrumentation, Presentation.
            External threats: Subject representativeness, Specification representativeness, Process differences.
        </dc:description.validity.evaluation>
    </dc:subject.planning>
```

(a) Applied Example Part 1.

```xml
    <dc:subject.operation>
        <dc:description.preparation>
            Two 75-minute training lectures covering SRS, SCR notation, and inspection procedures;
            training with ELEVATOR SRS.
        </dc:description.preparation>
        <dc:description.execution>
            Two experimental rounds per specification, including a 2-hour detection session
            and a 2-hour collection meeting.
        </dc:description.execution>
        <dc:description.data.validation>
            Fault keys, reviewer responsibility mapping, and fault detection summaries at both team
            and individual levels.
        </dc:description.data.validation>
        <dc:description.coverage>University of Maryland, USA.</dc:description.coverage>
    </dc:subject.operation>

    <dc:subject.analysis>
        <dc:description.descriptive.statistics>
            Average fault detection rate, meeting gain/loss rate,
            standard deviation.
        </dc:description.descriptive.statistics>
        <dc:description.data.set.reduction>
            Team performance analysis and individual performance analysis.
        </dc:description.data.set.reduction>
        <dc:description.hypothesis.testing>
            ANOVA for team performance; Wilcoxon-Mann-Whitney tests for individual performance;
            null hypothesis rejection for detection method (H1, H2 evaluation).
        </dc:description.hypothesis.testing>
    </dc:subject.analysis>

    <dc:subject.presentation>
        <dc:description.report>
            IEEE Transactions on Software Engineering, 21(6), 563-575, 1995.
        </dc:description.report>
        <dc:description.package>
            Laboratory kit, experimental materials, and data analysis resources.
        </dc:description.package>
        <dc:description.identifier>https://doi.org/10.1109/32.391380</dc:description.identifier>
        <dc:description.format>PDF document</dc:description.format>
        <dc:description.language>English</dc:description.language>
        <dc:description.source>IEEE</dc:description.source>
        <dc:description.rights>IEEE Copyright</dc:description.rights>
    </dc:subject.presentation>
</resource.experiment>
```

(b) Applied Example Part 2.

Figure 3. Applied Examples (Part 1 and Part 2).

5. Discussion of Results

The definition of DCEP-SE represents a significant advancement in addressing the challenges of standardization and interoperability in Experimental Software Engineering (ESE). The results obtained indicate that the profile can structure the documentation of experiments more clearly and uniformly, facilitating the retrieval, comparison, and reuse of experimental packages. This practical contribution is particularly relevant in light of recurring difficulties reported in the literature, such as the low rate of artifact sharing, the heterogeneity of descriptions, and the lack of standardized metadata, which compromise the replicability of studies [Timperley et al. 2021, Madeyski et al. 2017]. By mapping each phase of the experimental process to specific Dublin Core elements, DCEP-SE reduces ambiguities and promotes greater semantic consistency among descriptions.

From a scientific perspective, the main contribution lies in the methodological process employed to construct the profile. The progressive refinement, with the elimination of redundancies until reaching a minimal set of necessary elements, proves to be a replicable procedure for other domains. Unlike generic profiles such as DataCite, which emphasize aspects of data citation and persistence, or AGRIS, related to interoperability in the agricultural domain, DCEP-SE stands out for its suitability to the specific context of ESE, directly mapping variables, hypotheses, protocols, and results to the stages of the experimental cycle described by Wohlin et al. [Wohlin et al. 2024]. Thus, the study contributes not only a practical solution for the domain but also a methodological model that can be extended to create other application profiles based on Dublin Core.

The practical application in the classic experiment by Porter et al. [Porter et al. 1995] reinforces the feasibility and usefulness of DCEP-SE. The profile enabled the organization of information, from the initial characterization of the team and scope to the detailing of statistical analyzes and results, demonstrating how documentation gains clarity and granularity. This example suggests that the profile can be equally valuable for contemporary experiments, independent replications, or multi-site studies, contributing to building the empirical base of the field and fostering Open Science practices.

Nevertheless, some limitations must be considered. In addition to the non-systematic literature review already mentioned as a methodological restriction, the adoption of the profile may face cultural and practical barriers, as researchers may perceive the completion of additional metadata as extra effort. Furthermore, the validation of DCEP-SE has been carried out in a single classical study, making it necessary to test it in different experimental scenarios and in conjunction with widely used digital repositories such as Zenodo or OSF to verify its interoperability and adaptability in real contexts of publication and preservation.

As future directions, it is necessary to expand the empirical validation of the profile in recent ESE studies, evaluating its concrete contribution to increasing the replicability and reuse of experimental packages. Additionally, integrating DCEP-SE with the FAIR principles (Findable, Accessible, Interoperable, Reusable) is a promising avenue. The development of an automatic export mechanism is another possibility.

The availability of the metadata editor also opens the way for usability studies to understand researchers´ experiences in adopting the profile and to identify improvements that may facilitate its dissemination.

6. Final Remarks

The paper achieved its objectives by defining the DCEP-SE profile and developing a supporting metadata editor, which is currently under final evaluation. The general goal of creating a DC-based metadata system for documenting experimental data in ESE was fulfilled through DCEP-SE, which maps metadata elements to sub-phases of the experimentation process, enabling structured entry and file generation.

The first specific objective, analyzing existing DC-based metadata profiles, was addressed through a literature review, with AGRIS selected as the most suitable reference due to its clarity and systematic construction. The second objective, specifying a reusable process for developing a domain-specific profile, was achieved through progressive refinement, which reduced redundancy until only the essential elements remained.

Some limitations must be acknowledged. The literature review was non-systematic, which may have excluded relevant profiles and introduced selection bias. Finally, a metadata editor implementing DCEP-SE has been created to support researchers in recording experimental metadata and will soon be made publicly available.

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