German Medical Data Sciences 2024
R. Röhrig et al. (Eds.)

doi:10.3233/SHTI240852

Development of a SNOMED CT Mapping Process and Tool at a Data Integration Centre - Lessons Learned

Andrea RIEDEL[a,1], Noemi DEPPENWIESE[a], Lucas THIELE[a],
Hans-Ulrich PROKOSCH [a,b], and Annalena HERZOG[a]
[a] *Medical Centre for Information and Communication Technology, Universitätsklinikum Erlangen, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany*
[b] *Institute for Medical Informatics, Biometrics and Epidemiology, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany*
ORCiD-ID: Andrea Riedel https://orcid.org/0009-0006-9389-9482

Abstract. Introduction 16 million German-language free-text laboratory test results are the basis of the daily diagnostic routine of 17 laboratories within the University Hospital Erlangen. As part of the *Medical Informatics Initiative*, the local data integration centre is responsible for the accessibility of routine care data for medical research. Following the core data set, international interoperability standards such as *FHIR* and the English-language medical terminology *SNOMED CT* are used to create harmonised data. To represent each non-numeric laboratory test result within the base module profile *ObservationLab*, the need for a map and supporting tooling arose. **State of the Art** Due to the requirement of a n:n map and a data safety-compliant local instance, publicly available tools (e.g., *SNAP2SNOMED*) were insufficient. **Concept and Implementation** Therefore, we developed (1) an incremental mapping-validation process with different iteration cycles and (2) a customised mapping tool via *Microsoft Access*. Time, labour, and cost efficiency played a decisive role. First iterations were used to define requirements (e.g., multiple user access). **Lessons Learned** The successful process and tool implementation and the described lessons learned (e.g., cheat sheet) will assist other German hospitals in creating local maps for inter-consortia data exchange and research. In the future, qualitative and quantitative analysis results will be published.

Keywords. Terminology as Topic, Data Curation, Systematized Nomenclature of Medicine, Health Information Interoperability, Clinical Laboratory Information Systems

[1] Corresponding Author, Andrea Riedel, Medical Centre for Information and Communication Technology, Universitätsklinikum Erlangen, Friedrich-Alexander-Universität Erlangen-Nürnberg, Krankenhausstraße 12, 91054 Erlangen, Germany; E-mail: andrea.riedel@uk-erlangen.de.

1. Introduction

1.1. Background

Laboratory analytics is a crucial part of the daily hospital diagnostic routine. Next to quantitative numeric values, (semi-) qualitative analysis results as well as error messages or administrative comments lead to a great amount of free-text entries. The University Hospital Erlangen alone processes around 16 million free-text laboratory test results (status: November 2022). The data are highly heterogeneous due to the large number of 17 different laboratories. Each laboratory has its range of services, regulations or technical equipment. As part of the *Medical Informatics Initiative (MII)* [1], the University Hospital Erlangen has established a data integration centre (DIC) on-side to make German routine care data accessible for medical research and data analysis. Data quality and data safety play an essential role. To exchange harmonised data on hospital and national levels between more than 30 DIC, the *MII* created a core data set based on the *HL7 FHIR* standard including *Laboratory test results* as one of the seven base modules. It includes the profile *ObservationLab* [2] to represent a single laboratory result. To maintain interoperability in conjunction with *FHIR,* another international standard, *SNOMED CT (SCT)*, is used for representing non-numerical results. Especially for semantic interoperability the multilingual medical terminology *SCT* with more than 350,000 precoordinated concepts is one of the leading international standards in healthcare [3]. Therefore, one task of the team at the DIC Erlangen is mapping internal free-text laboratory test results to *SCT* [4].

The first attempts focused on approx. 300 most frequent free-text laboratory test results in Erlangen using a spreadsheet. The process employed one mapper and an interdisciplinary parallel double validation (technical expert and physician). The following iterations included project-related subsets such as the *GECCO* dataset [5] or comprehensive sets like the *TOP300 MII LOINCs* [6]. However, to generate a high-quality map for all textual results a more advanced and effective approach was needed.

1.2. Objective and Requirements

The DIC project has two intertwined main objectives: (1) The development of a mapping-validation process leading to high-quality maps for textual laboratory test results and (2) the implementation of a tool supporting this process. Time, labour, and cost efficiency concerning the large number of 16 million data entries played a decisive role. Therefore, the initial process prescribed that each map needs to be processed by at least three DIC employees, one person creating the initial map and two persons for validation. It was also clear that this process would not be conducted in discrete steps, but multiple people would act as mappers and validators simultaneously, with the stipulation that no one should validate their own maps or double-validate. The database implementation, mapping, and validation should be carried out by the team members independently and flexibly alongside their other DIC responsibilities. These initial process specifications already lead to several requirements: The tool needs to capture the status of the mapping and the user who performed the mapping/validation. It also must support multiple users accessing it simultaneously. Since the assistance by medical students was planned, it also needs to be simple to access and self-explaining to be used by non-technical staff. Other technical requirements are: First, the initial version of the tool should be available rapidly to begin the mapping. Second, to avoid data protection concerns, all data should be stored and processed within the hospital network. Still, it would need to be accessible by users remotely connecting to the hospital network as DIC staff does not only work on-site. Furthermore, it also needs to facilitate looking up existing maps, give an overview of all unmapped and mapped entries, and allow the export of all maps to enable further use e.g., in the data transformation pipeline. Content-wise, the tool needs to support a n:n map since the source consists of multiple values (the internal and *LOINC* test codes as well as the actual textual test result value) and it also maps to more values besides the *SCT* term, namely the *FHIR* observation status value [7] and possibly a *FHIR* data absent reason code [8]. It must also allow specifying the correlation and the type of map (whether there is a target *SCT* code, a data absent reason code, or both). Finally, it must adequately handle a large amount of source value combinations to be mapped without leading to performance issues.

2. State of the Art

2.1. Related Work

While there is no standard mapping process, other German research projects work with two independent mappers and subsequent consensus-building among the mappers [9]. However, other studies in the laboratory and healthcare context also employed one mapper and two validators instead [10,11]. For the mapping guidelines, to our knowledge no published works on the domain of German laboratory result data exist. There are however guidelines by *SNOMED International* [12,13] which give more general advice on mapping in the laboratory domain.

A basic approach for mapping is to use spreadsheets. Over the years, several more advanced mapping tools have been introduced. For example, the *Regenstrief Institute* created *RELMA* [14] to support the mapping of local laboratory test codes to *LOINC* codes. *RELMA* has already been used for this purpose at Erlangen [15]. Another available mapping tool is *SNAP2SNOMED* [16], which allows the creation of maps from any source list to *SCT*. *SNAP2SNOMED* is provided by *SNOMED International* as a web service and accessible to *SNOMED International* Members. It includes multi-user access to the map, support for a reviewing step after the initial map creation, and export of the map in multiple formats. *Snapper:Map* is developed by *CSIRO* and works on top of their *Ontoserver* terminology server [17]. It is a web-based application for the creation of maps to and from any terminology or code list. Although other mapping tools are available, the following shortcomings of the named tools represent common problems across all existing tools.

2.2. Shortcomings

Since a large portion of the mapping work would be contributed by medical students, the process needs to deal with fluctuating members. An approach using interdisciplinary double validation should ensure mapping quality on both the content and technical levels. As mentioned above, no exhaustive guideline exists for mapping German-language laboratory result data.

The initial spreadsheet on a shared drive quickly reached its limit in performance and usability due to the large amount of free-text entries. Therefore, we looked at other existing mapping tools like the ones listed in the previous section. Like many available tools, *RELMA* is tailored to a particular use case (here: mapping laboratory test codes to *LOINC*) that does not match the presented work. *SNAP2SNOMED* is a better fit, however, while it supports mapping arbitrary codes to *SCT*, it is restricted to 1:1 mapping scenarios. Additionally, it is hosted by *SNOMED International*, so data would be stored outside the hospital premises. *Snapper:Map* supports generic use cases, as long as they are 1:1 maps, which is not sufficient for this project. Generally, in cases where mapping tools were not strictly restricted to one specific use case, this restriction to 1:1 maps turned out to be the key exclusion criterion for existing tools.

3. Concept

3.1. Mapping-validation process

Concerning developing a mapping-validation process, an incremental approach consisting of different iteration cycles was chosen. Each of the subsequent iteration cycles started by separating the tasks.

The initial process consisted of one mapper and a double validation workflow. A mapping could be done either by a student assistant or a DIC expert with a medical or technical background. A validation team consisted of one student assistant and one DIC expert with a different background from the mapper. For an adequate laboratory-related knowledge background and a homogenous assistant group, only medical students who have passed the *First Medical State Examination* and are studying at least in the 5th semester were recruited.

Additionally, team members neither validated their own mappings nor validated the same entry twice. The map should only be modified by the second validator/DIC expert and documented in detail in a comment field. Overarching questions were noted in a central question-answer sheet for subsequent discussion in group meetings.

After each iteration, stepwise improvements of the workflow were planned for the next iteration cycle. In the meeting questions and problems were discussed, rules reflected or modified, and in the next iteration applied to new or old entries. Based on initial findings from the first mapping round a new concept for the second subsequent phase was developed, which is the focus of this paper.

3.2. Tool

An extract from the data warehouse (status: November 2022) served as a data basis, including all laboratory free-text results of the University Hospital Erlangen which were entered at least ten times.

The data were made accessible via a *Microsoft Access* database (Microsoft Corporation, Redmond, Washington, USA). To maintain better performance for various users, the front- and backend were split, a copy of the frontend was stored on the individual user desktop while the backend was stored on a central drive within the hospital network. While the frontend offered different forms for mapping and each of the validation steps, the backend contained the various tables.

As German translations were not available via the *SCT browser* [18] at the start of the project, precoordinated concepts should be searched via the English-language international edition accessed in the current latest version. If no precoordinated concept is found, the free-text entry should be represented by postcoordination, combining concepts according to the rules published in the *SCT machine readable concept model maintenance tool* [19]. Each map is created by combining information from multiple fields, which can be seen in the Graphical User Interface (GUI) (Fig. 1a): *LOINC* code, *LOINC* description, internal test code, unit, and finally the German laboratory free text test result [20]. Moreover, metadata as a map quality indicator should be stored alongside the actual map. A child of the concept *447247004 |SCT source code to target map code correlation value (foundation metadata concept)|* [21] must be chosen from a drop-down menu (Fig. 1b). As it is dependent on the textual result (since this may have indicated e.g. an error), a map to observation status [7] (Fig. 1c) via the drop-down menu is required as well as giving the data absent reason-related information [8] (Fig. 1d) in cases where this could not be represented using only *SCT*.

For each entry and phase, the processing status can be communicated using a predefined status option (*open*, *in process*, *done*; Fig. 1e). Concerns or suggestions can be expressed in a comment field (suggestions need to include the old code, the new code, and the reason for the change, Fig. 1f).

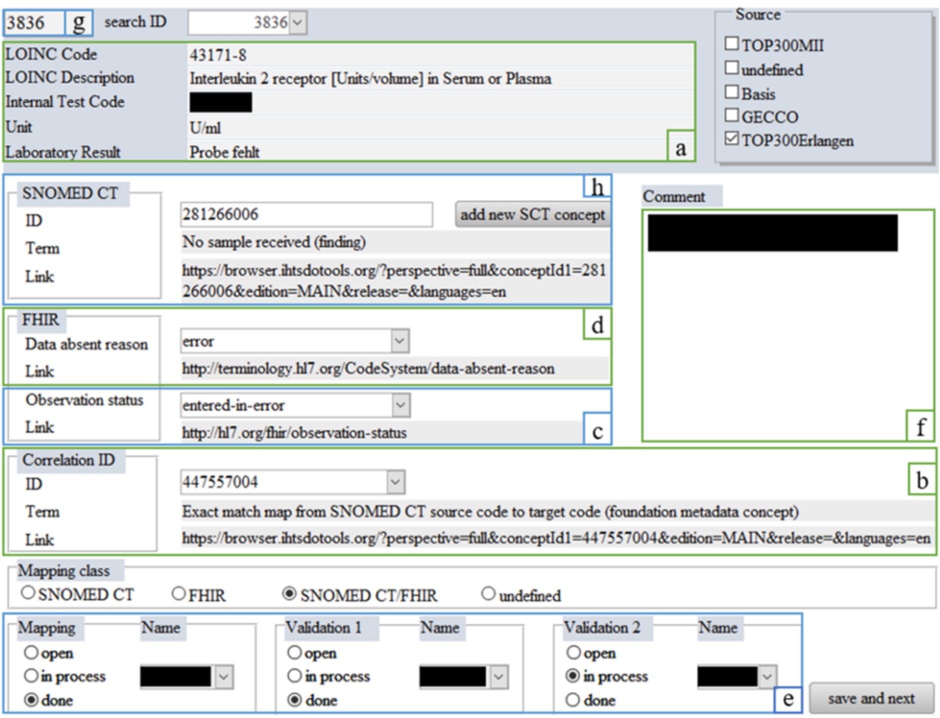

Figure 1. Graphical User Interface (GUI).

4. Implementation

4.1. Solution / Results

4.1.1. Mapping-validation process

After an introduction to *SCT* and the present project, six medical student assistants started mapping *SCT* codes together with three DIC employees. In the following stepwise double validation, the validators either approved the map entry (*done*, Fig.1e) or suggested different suggestions in the comment field (*in process*, Fig. 1e and Fig. 1f). In instances where no consensus could be achieved between the mapper and one of the validators or no clear mapping was available, each involved user contributed to a list of questions which was then discussed in a group meeting. The conclusions from these discussions were compiled into the ever-growing mapping cheat sheet.

Throughout the project, the initial mapping-validation process was improved several times. First, a third validation by the supervisor and a spreadsheet excerpt of the main table were introduced. Second, the meeting frequency was increased. Third, student assistants were allowed to map and validate in pairs. Fourth, specific subsets of test-result combinations (e.g. all microorganisms) were compiled. The final mapping-validation process is visualised in Fig. 2.

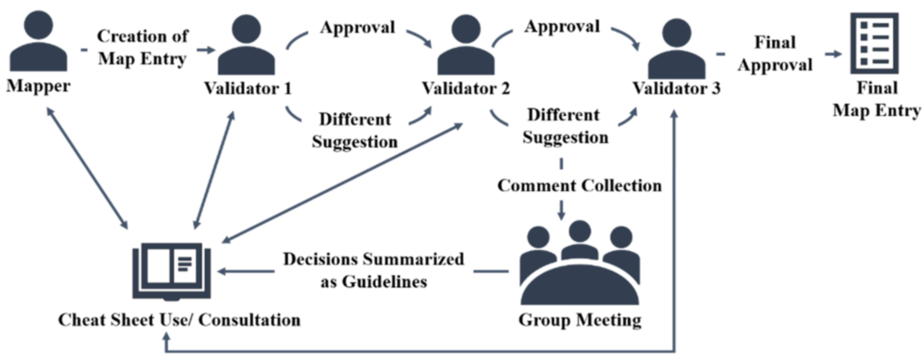

Figure 2. Final Mapping-validation-process (simplified).

4.1.2. Tool

The final *Microsoft Access* database consists of one file with various queries and forms, while the tables could be distinguished into three:

The **main table** is prefilled with the direct data export from the data warehouse. Each row represents a data set of a *LOINC* code, a laboratory site, and a German free-text test result (Fig. 1a). Thus, one data set may stand for one or more laboratory tests. Each data set was assigned a primary key for unique identification (Fig. 1g).

Four **supporting tables** are linked with the main table and describe the data sets to be mapped from the main table in more detail: a table for the *SCT ID* linked with associated information e.g., term and concept URL (Fig. 1h), a table for representing the quality of the maps (*correlation ID*, Fig. 1b), a table for the expressions of the data absent reason (*FHIR*, Fig. 1d), and a table for the expression of the observation status (*FHIR*, Fig. 1c). All supporting tables are displayed in the forms via drop-down menus to avoid incorrect entries, except for the *SCT ID,* which contains too many entries to be useful.

Process-supporting tables are also linked with the main table but have no connection in terms of content. They are valuable for the incremental mapping-validation process as modifications or adjustments (e.g. a new mapper) could be easily implemented. Each process stage (mapping, first/second/third validation) had a separate form with predefined fields for each item of a main table row (see section *3. Concept*). To ensure an incremental process each form only lists those data sets that comply with predefined rules e.g., data sets listed in the form *Validation 2* have already passed (*done*, Fig. 1e) through the two process stages *Mapping* and *Validation 1*.

4.2. System in Use

Nearly 16 million laboratory test results were processed between December 2020 and April 2024, while this work focused mainly on the last one and a half years. Around 12,000 different combinations of laboratory tests were already mapped to *LOINC* and German free text result entries. Therefore, around 1,200 different *SCT* codes were used of which 620 concepts are available in the first version of a German national Edition (2023-11-15) and approx. 250 are postcoordinated combinations. Currently, 10,500 data sets are mapped, which correspond to 87.5% of the database, while 12.5% are not mappable e.g. due to missing *SCT* concepts or postcoordination rules. For the mapping task, different versions of the *SCT* international edition were used, as the process was conducted over a longer period with a high number of data sets and worker fluctuation. Particularly, since the end of 2023 a significant increase in the number of finalised mappings and validations has been achieved with an increasing number of student assistants. In total, the database was used by 12 users for mapping and validation (one user was only present in the spreadsheet phase). In the previous phase, around two student assistants and 4-5 DIC employees were included for 16 months until the end of 2023, while in the last four months up to five student assistants and 2-3 DIC employees supported the task. In detail, between the 27th of December 2023 and the 20th of March 2024 an increase of 23.0% for mapping, 47.0% in the first validation and 38.0% in the second validation was achieved.

5. Lessons Learned

This work represents a successful tool and process development for a large amount of German-language laboratory test result maps in the *MII* context as part of different projects in a short period. Despite the complexity of the map, fast results were achieved using a simple tool like *Microsoft Access*. Lessons learned can be differentiated into three categories: (1) mapping-validation process, (2) tool implementation, and (3) additional findings. Many of the findings were only detected due to the large size of the data set.

With advancing progress, the complexity of mappings increased, as simple tasks were prioritised. Moreover, frequent versioning of the *SCT* edition could lead to new *SCT* concepts, descriptions, etc. This made a **re-validation** for changing **old mappings** e.g., postcoordinations due to newly available precoordinations necessary. Thus, a **cheat sheet** with additional internal rules was created and constantly updated with each iteration. It served as internal guidance for new and experienced users. Due to economic reasons, repetitive tasks such as creating 1:1 maps for organisms or concept changes according to the cheat sheet were assigned to student assistants. Especially after the *First Medical State Examination*, students proved to have valuable knowledge regarding laboratory research. Therefore, it became apparent that **double validation teams** of students and DIC experts were no longer strictly necessary. Nevertheless, at the start a double validation by an interdisciplinary team was still required to enable an interdisciplinary exchange, confirming the findings of other projects e.g. *RES-Q+* [11]. Moreover, the definition of a **supervisor** (*AR*, medical and technical expertise) proved useful in maintaining an overview, harmonising similar entries of different tests, or creating categories of various entries of the same test during the process. A **third final validation** by the supervisor will be added to the process as well. With an increasing number of student assistants, the task division proved to be more complex. On the one hand, the percentage of mapping does not reflect individual work effort as some mappings are very similar and can be mapped at once, while others have high complexity. On the other hand, later tasks can depend on content and not workflow status; so, three user forms need to be opened individually. Therefore, the supervisor needs to define the workload to detect discrepancies, control whether the members followed the cheat sheet rules, and connect similar status tasks.

During the project, we identified and partially implemented new **tooling requirements**. E.g. linking URLs to concepts (*SCT, FHIR*) has proven unnecessary. Instead, a timestamp of the respective activities is needed, due to frequent versioning of the *SCT browser*. Also, with increasing mapping complexity, it became necessary to have an **overview** of similar entries and a filter function e.g. to organise task responsibilities without manipulating the original main table of the database. Both options should be integrated into further tool versions. The large number of users and the remote use of the database caused major initial performance issues. After identifying unstable connections to the hospital network as the underlying problem, an **indirect connection process for remote users was set up**. This significantly improved mapping speed. When working with the database, the database **query function** proved useful for providing quick and detailed analysis e.g., of the mapping progress. Development and optimisation are closely linked and interactive in a routine operation such as the DIC. Especially for this database, rapid adaptions were necessary to maintain the workflow, considering the number of incrementally recruited DIC employees. Under the given circumstances of the previously mentioned iterations, performance metrics were out of scope. However, it is planned to identify further improvement potential and measure effectiveness for the following sprints with pre-defined key parameters (e.g., the number of new maps in pre-defined sprint time).

The time-consuming **manual German-English translation** was a major stalling factor, as an official German *SCT* translation was missing or limited to specific topics during project time. The **monthly versioning of *SCT*** caused a complex maintenance challenge by adding new concepts, descriptions, etc. Previous postcoordinations may have been made obsolete by simple precoordinations or concepts could be deactivated. Future tools should implement functionality to support these updates. Due to the occasionally **low performance and downtime of the *SCT browser,*** a local installation is recommended. Better usability increases the motivation and speed of users. Although the tool supports a n:n map, it is still **restricted to a very specific use case**. While it may be usable by other DIC requiring the same source and target data models, a more generic solution is still needed.

6. Conclusion

When designing (1) a mapping-validation process and (2) implementing a supporting tool, it is difficult to anticipate all requirements from the beginning. Instead, both parts need to be flexible due to adapting to changing circumstances. The following influencing factors need to be considered: In the (1) mapping-validation process a supervisor should incorporate a central position of task distribution and harmonisation over a multiple validation steps process. Especially, the supervisor's third validation is an essential gatekeeper due to dynamic *SCT* versioning. An up-to-date rule summary in the form of a cheat sheet supports the mapper/validator efficiently. The (2) tool implementation should always allow flexible integration of new requirements such as time stamps, filter functions, and especially overview and query functions. For an efficient workflow with multiple users secure and easy remote access is strongly recommended. Influencing external findings are the limited national German edition which leads to individual time-consuming manual English-German translation and the general monthly versioning of *SCT*. The low performance and downtime of the *SCT browser* is a limitation of the user's performance and should be replaced by alternatives. Any database with a singular project focus always includes a n:n restriction to a specific use case.

It is possible to quickly develop a custom mapping tool solution using *Microsoft Access* without deep technical knowledge. As a temporary solution, the database will be expanded to all local *SCT* mappings besides laboratory test results. Currently, a cross-terminology tool which will be built from the presented experience is under design.

As cross-site exchange is a leading goal of the *MII*, the present work will help other German DIC replicate and facilitate their local implementation of *SCT* for non-numerical laboratory test results based on the described concept and material. The mapping cheat sheet, the database structure, and the final mappings will be made available to researchers upon request. The final mappings for German laboratory data are the first of their kind for this amount of data e.g., to train local machine learning models for accelerated data harmonisation and standardisation under data security standards. *SCT* mappings could be accelerated by further versions of the German national edition and an automated pre-population of *SCT* concepts through a local machine learning model. Further publications on this work will give a detailed overview of the quantitative and qualitative analysis of the mapping results.

Declarations

Conflict of Interest

The authors declare, that there is no conflict of interest.

Contributions of the Authors

AR development concept, supervision contextual mapping-validation process, and writing manuscript; AR and AH building initial prototype and analysis scripts; AH technical maintenance database; ND representation with FHIR; LK, AR, AH, and ND user feedback; all authors input on manuscript. All authors have approved the manuscript as submitted and accept responsibility for the scientific integrity of the work. The present work was performed in (partial) fulfilment of the requirements for obtaining the degree

"Dr. rer. biol. hum." from the Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) (AR, ND).

Acknowledgement

Funding: NUM 2.0 (Grant No: 01KX2121) (AR, AH) and GeMTeX (Grant No: 01ZZ2314G) (LK). We would like to thank all involved mappers/validators and ETL experts for their valuable user feedback and support.

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