An Interactive Tutoring System for Training Software Refactoring

Thorsten Haendler, Gustaf Neumann and Fiodor Smirnov
Institute for Information Systems and New Media,
Vienna University of Economics and Business (WU), Austria
{firstname.lastname}@wu.ac.at

Keywords: Intelligent Tutoring System, Software Refactoring, Software Design, Code Visualization, Software-Engineering Education and Training, Unified Modeling Language (UML2), Interactive Training Environment.

Abstract: Although considered useful and important, software refactoring is often neglected in practice because of the perceived risks and difficulties of performing it. A way to address these challenges can be seen in promoting developers' practical competences. In this paper, we propose an approach for an interactive training environment for addressing practical competences in software refactoring. In particular, we present a tutoring system that provides immediate feedback to the users (e.g. university students or software developers) regarding the software-design quality and the functional correctness of the (modified) source code. After each code modification (refactoring step), the user can review the results of run-time regression tests and compare the actual software design (as-is) with the targeted design (to-be) in order to check quality improvement. For this purpose, structural and behavioral diagrams of the Unified Modeling Language (UML2) representing the as-is software design are automatically reverse-engineered from source code. The to-be design diagrams (also in UML) can be pre-specified by the instructor. We illustrate the usability of the approach for training competences in refactoring via short application scenarios and describe exemplary learning paths. Moreover, we provide a web-based software-technical implementation in Java (called refacTutor) to demonstrate the technical feasibility of the approach. Finally, limitations and further potential of the approach are discussed.

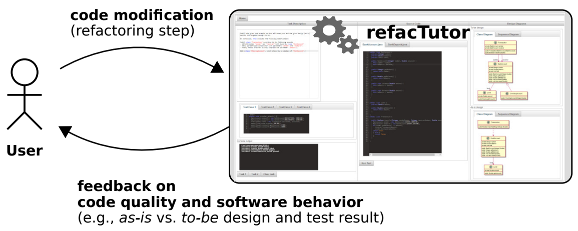
1 INTRODUCTION

As a result of time pressure in software projects, priority is often given to implementing new features rather than ensuring code quality (Martini et al., 2014). In the long run, this leads to *software aging* (Parnas, 1994) and increased *technical debt* with the consequence of increased maintenance costs on the software system (i.e. *debt interest*) (Kruchten et al., 2012). A popular technique for code-quality assurance is software refactoring, which aims at improving code quality by restructuring the source code while preserving the external system behavior (Opdyke, 1992; Fowler et al., 1999). Several kinds of flaws (such as code smells) can negatively impact code quality and are thus candidates for software refactoring (Alves et al., 2016). Besides kinds of smells that are relatively simple to identify and to refactor (e.g. stylistic code smells), others are more complex and difficult to identify, to assess and to refactor, such as smells in software design and architecture (Fowler et al., 1999; Suryanarayana et al., 2014; Nord et al., 2012) Although refactoring is considered useful and important, it is often neglected in practice due to several barriers, among which are (perceived by software developers) the difficulty of performing refactoring, the risk of introducing an error into a previously correctly working software system, and a lack of adequate tool support (Tempero et al., 2017). These barriers pose challenges with regard to improving refactoring tools and promoting the skills of developers.

On the one hand, in last years, several tools have been proposed that apply static analysis for identifying smells via certain metrics and benchmarks (e.g. level of coupling between system elements) or supporting in planning and performing the actual refactoring (steps), such as *JDeodorant* (Tsantalis et al., 2008) and *DECOR* (Moha et al., 2010), as well as for measuring and quantifying their impact in terms of technical debt, such as *SonarQube* (Campbell and Papapetrou, 2013) or *JArchitect* (CoderGears, 2018). However, for more complex kinds of smells (e.g. on the level of software design and architecture) the smell detection and refactoring is difficult. Thus, these tools only cover a modest amount of smells (Fernandes et al., 2016; Fontana et al., 2012) and tend to produce *false positives* (Fontana et al., 2016) (which e.g. represent constructs intentionally used by the developer with symptoms similar to smells, such as certain design patterns). In addition, the decision what and how to refactor also depends on domain knowledge (e.g. regarding design rationale) provided by human experts such as software architects. Due to these issues, the refactoring process is still challenging and requires human expertise.

On the other hand, so far only little attention has been paid in research to education and training in the field of software refactoring. Besides textbooks with best practices and rules on how to identify and to remove smells via refactoring, e.g. (Fowler et al., 1999), there are only a few approaches (see Section 6) for supporting developers in accomplishing or improving practical and higher-level competences such as *application*, *analysis* and *evaluation* according to Bloom's taxonomy of cognitive learning objectives; see, e.g. (Bloom et al., 1956; Krathwohl, 2002).

In this paper, we propose an approach for an interactive learning environment for training practical competences in software refactoring. In particular, we present a tutoring system that provides immediate feedback and decision-support regarding both the software-design quality and the functional correctness of the source code modified by the user (see Fig. 1).



code modification
(refactoring step)
refacTutor
User
feedback on
code quality and software behavior
(e.g., as-is vs. to-be design and test result)

Figure 1: Exercise interaction supported by tutoring system.

Driven by a refactoring task defined by the instructor, after each refactoring step, the user can review the results of run-time regression tests (e.g. prespecified by the instructor; in order to check that no error has been introduced) and compare the actual software design (*as-is*) with the intended design (*to-be*; in order to check quality improvement). For this purpose, structural and behavioral software-design diagrams of the Unified Modeling Language (UML2) (Object Management Group, 2015) representing the as-is software design are automatically reverse-engineered from source code. The to-be design diagrams (also in UML) can be pre-specified by the instructor. UML is the *de-facto* standard for modeling and documenting structural and behavioral aspects of software design. There is evidence that UML design diagrams are beneficial for understanding software design (issues) (Arisholm et al., 2006; Scanniello et al., 2018; Haendler, 2018). This way, the approach primarily addresses the refactoring of issues on the level of software design and architecture. Moreover, the code visualization supports in building and questioning users' mental models, see, e.g. (Cañas et al., 1994; George, 2000). In addition, the system optionally reports on other quality aspects provided by quality-analysis tools (Campbell and Papapetrou, 2013).

In order to illustrate the usability for teaching and training refactoring competences, we describe exemplary learning paths, specify the corresponding exercise-interaction workflow and draw exemplary application scenarios (based on different learning objectives and tasks and with corresponding settings (configuration options) for decision support and feedback). We also introduce a proof-of-concept implementation in Java (called *refacTutor*[1]) in terms of a web-based development environment. Its application is demonstrated via a short exercise example. In the following Section 2, a short conceptual overview of the proposed approach is given.

2 CONCEPTUAL OVERVIEW

Fig. 2 depicts an overview of the tutoring-system infrastructure in terms of technical components and artifacts used, created or modified by instructor and/or user respectively.

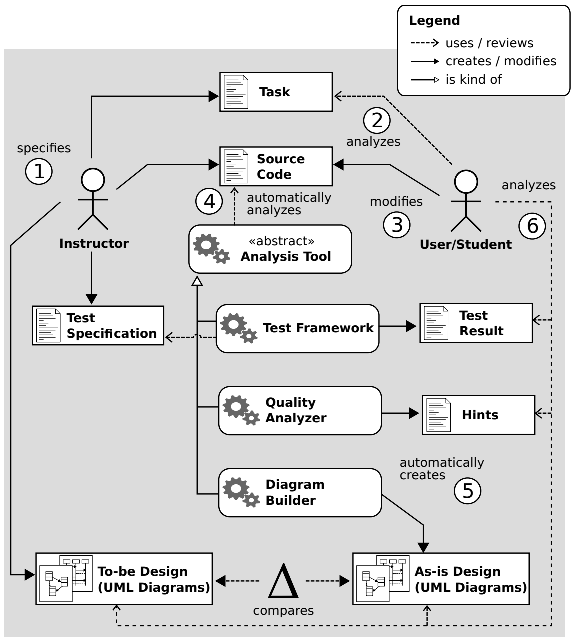


Figure 2: Overview of key components and artifacts of interactive tutoring system for training software refactoring.

[1]See Section 5. The software prototype is available for download from http://refactoringgames.com/refactutor

Focused on certain learning objectives (for details, also see Sections 3 and 4), the instructor at first specifies a task, prepares the initial source code for exercise, specifies (or re-uses an existing) test script, and specifies the *to-be* software design (see step ① in Fig. 2). The user's exercise then starts by analyzing the task (step ②). After each code modification (step ③), the user can review several kinds of feedback created by different analysis tools that analyze the code (see steps ④ to ⑥). These analyzers consist of a test framework for checking the functional correctness (test result), a quality analyzer that examines the code using pre-configured quality metrics (for providing hints on quality issues), and a diagram builder that derives (reverse-engineers) diagrams from source code and reflects the current *as-is* software design. This way, the tutoring system supports a cyclic exercise workflow of steps ③ to ⑥.

Structure. The remainder of this paper is structured as follows. In Section 3, the applied conceptual framework of the interactive tutoring system (including competences and learning paths, exercises, code modification as well as feedback mechanisms) are elaborated in detail. Section 4 illustrates the usability of the training environment for two exercise scenarios (i.e. design refactoring and test-driven development). Then, in Section 5, we present a proof-of-concept implementation in Java; including a detailed exercise example. In Section 6, related approaches are discussed. Section 7 reflects limitations and further potential of the approach and Section 8 concludes the paper.

3 INTERACTIVE TUTORING ENVIRONMENT

Fig. 3 gives an overview of important conceptual aspects for training software refactoring. The model is structured into four layers that concretize from an exemplary learning and training path Ⓐ (built on exemplary environments) via the exercises performed by the user Ⓑ to refactoring paths and system states Ⓒ and finally views on system states Ⓓ (feedback and decision support). The corresponding aspects are described below in detail.

3.1 Learning Objectives and Paths

The learning activity sequence (IMS Global Consortium, 2003) (depicted on the top layer Ⓐ in Fig. 3) illustrates an exemplary learning path for software refactoring by sequence multiple exercise units,

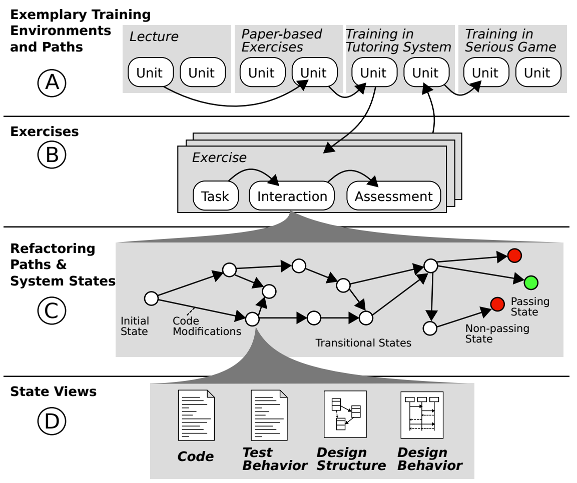


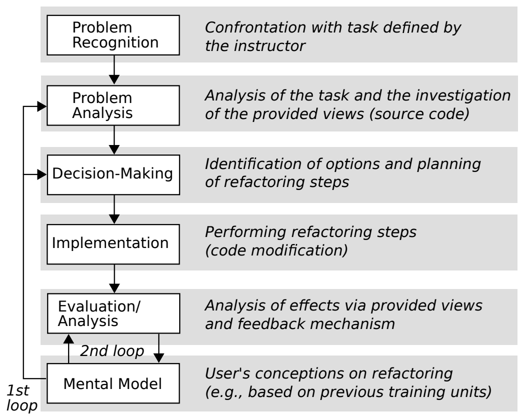
Figure 3: Layers of training refactoring via tutoring system from exemplary learning paths with refactoring exercises to applied feedback mechanism.

which base on different learning environments. The path can be driven by certain learning objectives, e.g. oriented to Bloom's taxonomy of cognitive learning objectives (Krathwohl, 2002). For instance, via **lecture** based on best practices and rules provided by a refactoring textbook, e.g. (Suryanarayana et al., 2014), basic competences (i.e. *knowledge* and *comprehension*) may be addressed, e.g. the (theoretical) understanding of rules for identifying refactoring candidates and for performing refactoring steps. For *applying* the comprehended techniques, e.g. units with **paper-based exercises (PBE)** can follow. In order to actually apply and improve practical competences on executable code (via editor), a **tutoring system** then can be used (see below). Moreover, via playing **serious games** (providing or simulating real-world conditions, such as a large code base) (Haendler and Neumann, 2019), further higher-level competences can be acquired such as *analysis* and *evaluation* (e.g. while developing and applying refactoring strategies for prioritizing smell candidates and refatoring options). This exemplary path along different training environments demonstrates that the proposed tutoring-system approach has to be seen as a complement to other approaches, each focusing on certain competence levels.

3.2 Structure of Exercises

A unit might generally consist of several exercises. Each exercise of the proposed tutoring system (see the second layer Ⓑ in Fig. 3) has a certain sequence consisting of the *task* (instruction) defined by the instructor, the exercise *interaction* of the user with the tutoring system and the exercise *assessment*, which will be explained in detail below.

Task. The task defines the actual instructions to be performed by the user. The instructions might be oriented to e.g. a challenge to be solved (e.g. to remove a certain smell), a goal to be achieved (e.g. to realize a certain design structure), or instructions for concrete modification actions (e.g. to perform an EXTRACT-METHOD refactoring). For examples with further details, also see Section 4).


Problem Recognition
Confrontation with task defined by the instructor
Problem Analysis
Analysis of the task and the investigation of the provided views (source code)
Decision-Making
Identification of options and planning of refactoring steps
Implementation
Performing refactoring steps (code modification)
Evaluation/ Analysis
Analysis of effects via provided views and feedback mechanism
2nd loop
Mental Model
User's conceptions on refactoring (e.g., based on previous training units)
1st loop
Figure 4: Refactoring-exercise workflow as double-loop learning and decision-making cycle supported by the tutoring system.

Interaction. The exercise interaction represents a cycle of analysis and actions performed by the user which is built on feedback provided by the tutoring system. Fig. 4 represents the workflow of the exercise interaction in terms of a double-loop learning and decision-making cycle supported by the approach; also see (Haendler and Frysak, 2018). Driven by the specific task (*problem recognition*) and based on the user's *mental model*, the user analyses the task and investigates the provided views (e.g. design diagrams). After *analysis*, the user identifies options and plans for refactoring (*decision making*). In this course, the user selects a certain option for code modification and plans the particular steps for performing them (*implementation*). After the code has been modified, the user analyzes the feedback given by the tutoring system (*evaluation*). This workflow supports a double-loop learning (Argyris, 1977). Through previous learning and practice experiences, the users have built a certain mental model (Cañas et al., 1994) on performing software refactoring, on which the analysis and the decisions for planned modifications are built (*first loop*), e.g. how to modify the code structure in order to remove the code or design smell. After modification, the feedback (e.g. in terms of test result, the comparison of the *as-is* with the *to-be* design diagrams) impacts the user's mental model and allows for scrutinizing and adapting the decision-making rules (*second loop*). This way, the cycle allows an (inter-) active learning for promoting practical competences.

Assessment. The exercise assessment provides means for assessing the outcome of the user's actions in terms of feedback for both the instructor as well as the user. Basically, it is checked whether the as-is design conforms the to-be design and whether the tests pass. The verification of the design quality can be performed manually by the instructor (by visually comparing the diagrams) or automatically by using analysis tools to check for differences between the diagrams; or applying additional quality-analysis tools (see below). Moreover, the time for completing the exercise can be measured.

3.3 Code Modifications and System States

During exercise interaction, the system under analysis (SUA) can take different system states (see ⓒ in Fig. 3). The states can be classified into the *initial state* ($\mathrm{S}_{\mathrm{INITIAL}}$), the *final state(s)* (i.e. $\mathrm{S}_{\mathrm{FINAL(PASSING)}}$ and $\mathrm{S}_{\mathrm{FINAL(NON\text{-}PASSING)}}$) and multiple *transitional states* ($\mathrm{S}_{\mathrm{TRANSITIONAL}}$). In particular, the **initial state** $\mathrm{S}_{\mathrm{INITIAL}}$ represents the system at the beginning (e.g. as prepared by the instructor). Each actual or possible modification to be performed on a certain state then leads to a certain following state ($\mathrm{S}_{\mathrm{TRANSITIONAL}}$). Depending on the kind of task and smell, there are different ways of achieving the defined exercise goal. As mentioned above, for more complex smells several options and sequences for achieving a desired design can exist, such as for some types of software-design smells (Suryanarayana et al., 2014). This way, the options and steps of possible modifications can be represented via a graph structure (i.e. modifications as edges, states as nodes). The performance of one user (via several refactoring steps starting from and/or leading to a $\mathrm{S}_{\mathrm{TRANSITIONAL}}$) then draws a concrete path through this graph. The **final state** can either be passing ($\mathrm{S}_{\mathrm{FINAL(PASSING)}}$) (i.e. fulfilling the quality standards, e.g. defined by *to-be* design diagrams, and passing the tests) or failing ($\mathrm{S}_{\mathrm{FINAL(NON\text{-}PASSING)}}$). For each state, several aspects are important for refactoring which are reflected by selected views (see below).

3.4 Views on System States

Oriented to viewpoint models applied in software architecture such as (Kruchten, 1995), we apply a *viewpoint model for refactoring* that includes the following four views on system states, i.e. *code, test behavior* as well as *design structure and behavior* (see Ⓓ in Fig. 2). The views conform to the viewpoint model depicted in Fig. 5 and serve as feedback and decision support for the user on each system state. In particular, there is evidence that for identifying and assessing software design smells (such as ABSTRACTION or MODULARIZATION smells), a combination of UML class diagrams (providing inter-class couplings evoked by method-call dependencies) and sequence diagrams (representing run-time scenarios) is appropriate (Haendler, 2018). The viewpoint model depicted in Fig. 5 reflects the views on system states.

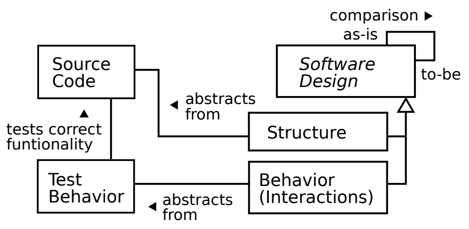


Figure 5: Applied viewpoint model for refactoring.

In addition to the **source code** (modified by the user), the other views are provided by applying the following tools and techniques.

- The **test behavior** is specified (in terms of a test script) using a certain test framework (e.g. XUnit or scenario-based tests). By performing the tests after each (important) modification (regression testing) the functional correctness of the code is ensured. Feedback is returned to the user in terms of the test result.
- For automatically deriving (a.k.a. reverse-engineering) the design diagrams representing the as-is software design of the source code, (automatic) static and dynamic analysis techniques are applied, see, e.g. (Richner and Ducasse, 1999; Kollmann et al., 2002; Haendler et al., 2015). The *Unified Modeling Language* (UML)(Object Management Group, 2015) is the *de-facto* standard for documenting software design. For representing **design structure**, UML class diagrams are extracted from source code; for **design behavior**, UML sequence diagrams are derived from execution traces. For further details on the derivation techniques and the resulting diagrams, see Section 5.
- In addition, also *software-quality analyzers* (e.g. *SonarQube* (Campbell and Papapetrou, 2013)) can be used to identify quality issues (such as smells) as well as to measure and quantify the technical debt score, which both then can be presented as hints or feedback to the user.

4 APPLICATION SCENARIOS

In order to illustrate the feasibility of the proposed tutoring-system approach for teaching and training software refactoring, two possible application scenarios are described. In Table 1, exemplary tasks with corresponding values of views and other exercise aspects are specified for two scenarios, i.e. *(a) design refactoring* and *(b) test-driven development (TDD)*.

Table 1: Exemplary exercise scenarios: (a) design refactoring and (b) test-driven development.

Aspects and Views	***Design Refactoring***	***Test-driven Development (TDD)***
Task	Refactor the given (smelly) source code in order to achieve the defined to-be design	Implement the given to-be design in code so that also the given tests pass
Target Competence	Analyze software design and plan & perform refactoring steps for removing a given smell	Apply the *red–green-refactor* steps (to realize the defined to-be design and test behavior)
Prerequisite Competence	Knowledge on refactoring options for given smell type as well as on notations and meaning of UML diagrams	Knowledge on refactoring options for given smell type as well as on notations and meaning of UML diagrams
Code ($\text{S}_{\text{INITIAL}}$)	Code with design smells	No code given
As-is-Design ($\text{S}_{\text{INITIAL}}$)	Representing design smells	No as-is-design available
As-is-Design ($\text{S}_{\text{FINAL(PASSING)}}$)	Conforming to to-be design	Conforming to to-be design
Tests	Tests pass in ($\text{S}_{\text{INITIAL}}$) and in ($\text{S}_{\text{FINAL(PASSING)}}$)	Tests fail in ($\text{S}_{\text{INITIAL}}$), but pass in ($\text{S}_{\text{FINAL(PASSING)}}$)
Assessment	As-is and to-be design are identical and all tests pass	As-is and to-be design are identical and all tests pass

4.1 Design Refactoring

First, consider the instructor aims at fostering the practical competences of analyzing the software design and performing refactoring steps (i.e. *application* and *analysis*, see *target competences* in Table 1). In this case, a possible training scenario can be realized by presenting a piece of source code that behaves as intended (i.e. runtime tests pass), but with smelly design structure (i.e. as-is design and to-be design are different). The user's task then is to refactor the given code in order to realize the specified targeted design. As important prerequisite, the user needs to bring along the competences to already (theoretically) know the rules for refactoring and to analyze UML diagrams. Fig. 6 depicts the values of different system states while performing the exercise (also see Section 3.3 and 3.4). At the beginning ($\text{S}_{\text{INITIAL}}$), the tests pass, but code and design are smelly by containing, e.g. a MULTIFACETEDABSTRACTION smell (Suryanarayana et al., 2014). During the (path of) refactorings (e.g. by applying corresponding EXTRACTCLASS and/or MOVEMETHOD / MOVEFIELD refactorings (Fowler et al., 1999)), the values of the views can differ (box in the middle). Characteristic for a non-passing final state or the transitional states is that at least one view (e.g. test, design structure or behavior) does not meet the requirements. In turn, a passing final state fulfills the requirements for all view values (box on the right-hand side).

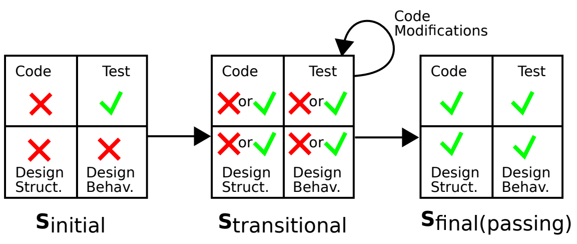


Figure 6: States with view values for the exercise scenario on design refactoring.

4.2 Test-driven Development

Another application example can be seen in test-driven development. Consider the situation that the user shall improve her competences in performing the *red–green–refactor* cycle typical for test-driven development (Beck, 2003), which also has been identified as challenging for teaching and training (Mugridge, 2003). This cycle includes the activities to specify and run tests that reflect the intended behavior (which first do not pass; *red*), then implement (extend) the code to pass the tests (i.e. *green*), and finally modify the code in order to improve design quality (i.e. *refactor*). For this purpose, corresponding runtime tests and the intended to-be design are prepared by the instructor. The user's task then is to realize the intended behavior and design by implementing and modifying the source code. Fig. 7 depicts the view values of the different system states.

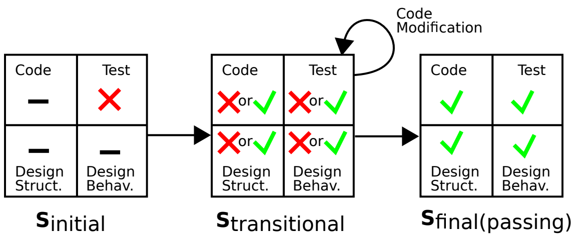


Figure 7: States with view values for the exercise scenario on test-driven development.

Besides these two exemplary scenarios, multiple other scenarios can be specified by varying the values of the exercise aspects and views (see Table 1).

5 SOFTWARE PROTOTYPE

In order to demonstrate the technical feasibility, we introduce our software prototype **refacTutor**[2] that realizes key aspects of the infrastructure presented in Fig. 2. In the following, we focus on applied technologies, the derivation of UML class diagrams reflecting the *as-is* design, the graphical user interface (GUI), and a concrete exercise example.

5.1 Applied Technologies

We implemented a software prototype as a web-based application using *Java Enterprise Edition (EE)* to demonstrate the feasibility of the proposed concept. *Java* is also the supported language for the refactoring exercises. As editor for code modification the *Ace Editor* (Ajax.org, 2019) has been integrated, which is a flexible browser-based code editor written in *JavaScript*. After test run, the entered code is then passed to the server for further processing. For compiling the Java code, we applied *InMemoryJavaCompiler* (Trung, 2017), a GitHub repository that provides a sample of utility classes allowing compilation of Java sources in memory. The compiled classes are then analyzed using *Java Reflection* (Forman and Forman, 2004) in order to extract information on code structure. The correct behavior is verified via *JUnit* tests (Gamma et al., 1999). Relevant exercise information is stored in *XML* files including task description, source code, test script, and information for UML diagrams (see below).

5.2 Design-Diagram Derivation

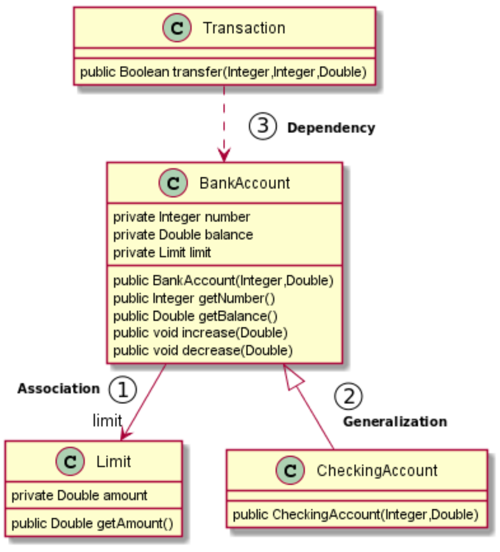
For automatically creating the as-is design diagrams, the extracted information is transferred to an integrated diagram editor. *PlantUML* (Roques, 2017) is an open-source and *Java*-based UML diagram editor that allows for passing plain text in terms of a simple DSL for creating graphical UML diagrams (such as class and sequence diagrams), e.g. in PNG or SVG format. *PlantUML* also manages the efficient and aesthetic composition of diagram elements.

Fig. 8 depicts an application example of source code to be refactored (left-hand side, Listing 1) with

[2]The software prototype is available for download from http://refactoringgames.com/refactutor

Listing 1: Exemplary Java code.

```
 1 public class BankAccount {
 2   private Integer number;
 3   private Double balance;
 4   private Limit limit; //(1)
 5   public BankAccount(Integer number, Double balance) {
 6     this.number = number;
 7     this.balance = balance;
 8   }
 9   [...]
10 }
11 public class CheckingAccount extends BankAccount { //(2)
12   [...]
13 }
14 public class Limit {
15   [...]
16 }
17 public class Transaction {
18   public Boolean transfer(Integer senderNumber, Integer
        receiverNumber, Double amount) {
19     BankAccount sender = new BankAccount(123456); //(3)
20     BankAccount receiver = new BankAccount(234567);
21     if(sender.getBalance() >= amount){
22       receiver.increase(amount);
23       sender.decrease(amount);
24       return true;
25     } else {return false;}
26   }
27 }
```



C Transaction
public Boolean transfer(Integer,Integer,Double)
③ Dependency
C BankAccount
private Integer number
private Double balance
private Limit limit
public BankAccount(Integer,Double)
public Integer getNumber()
public Double getBalance()
public void increase(Double)
public void decrease(Double)
Association ①
limit
② Generalization
C Limit
private Double amount
public Double getAmount()
C CheckingAccount
public CheckingAccount(Integer,Double)

Figure 8: Listing with exemplary Java code fragment for a refactoring task (left-hand side) and UML class diagram (right-hand side) representing the as-is design automatically derived from source code and visualized using PlantUML.

as-is design diagram (reflecting the current state of code) in terms of a **UML class diagrams** (right-hand side). In particular, the (derived) class diagrams provide *associations* in terms of references to other classes. For example, see ① in the diagram and line 4 in the listing in Fig. 8. *Generalizations* represent is-a relationships (between sub-classes and super-classes); see ② in the diagram and line 11 in the listing. Moreover, the derived class diagrams also provide call (or usage) *dependencies* between classes (see ③), which, e.g. represent inter-class calls of attributes or methods from within a method (see lines 19 and 20 in the listing in Fig. 8). For deriving **UML sequence diagrams**, we apply dynamic reverse-engineering techniques based on the execution traces triggered by the runtime tests, already described and demonstrated in (Haendler et al., 2015) and (Haendler et al., 2017). As explained in Section 3.4, a combination of UML class and sequence diagrams can support in identifying and assessing issues in software design or architecture (Haendler, 2018).

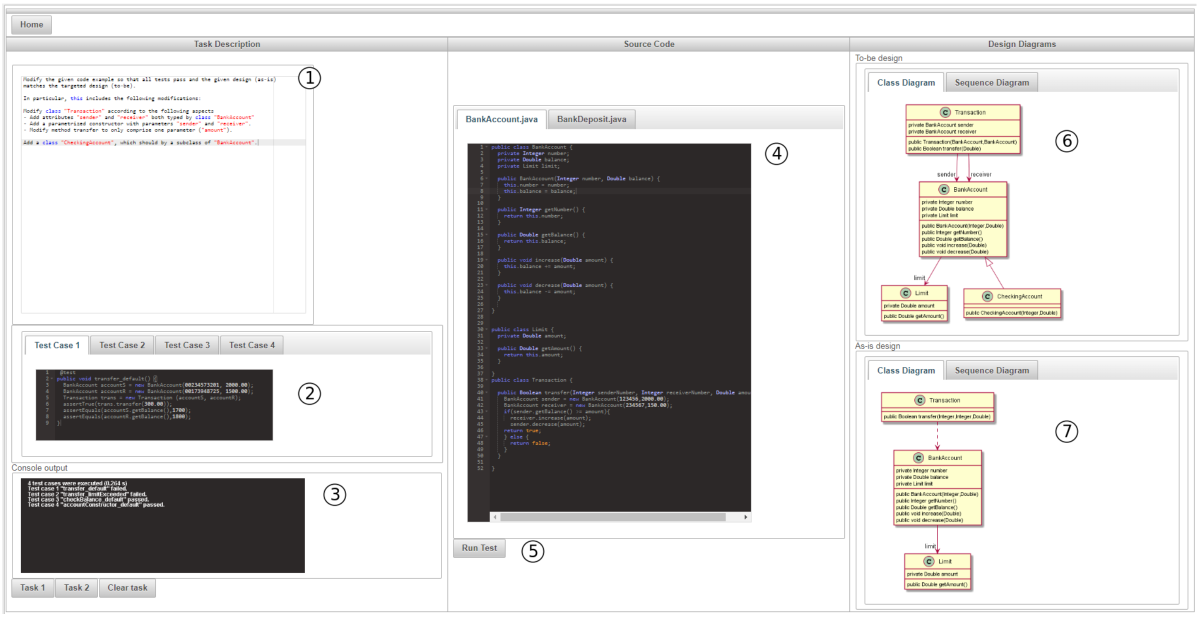
5.3 GUI

As outlined in the overview depicted in Fig. 2, the prototype provides GUI perspectives for instructors configuring and preparing exercises and for users performing the exercises. Each role has a specific browser-based dashboard with multiple views (a.k.a. widgets) on different artifacts (as described in Fig. 2). Fig. 9 depicts the user's perspective with provided views and an exercise example (which is detailed in Section 5.4). In particular, the user's perspective comprises a view on the task description (as defined by the instructor; see ① in Fig. 9). In ②, the tests scripts of the (tabbed) *JUnit* test cases are presented. The console output in ③ reports on the test result and additional hints. The code editor (see ④ in 9) provides the source code to be modified by the user (with tabs for multiple source files). Via the button in ⑤, the user can trigger the execution of the runtime tests. For both the to-be design (defined by the instructor beforehand; see ⑥) and the actual as-is design (automatically derived after and while test execution and reflecting the state of the source code; see ⑦), also tabs for class and sequence diagrams are provided. The teacher's perspective is quite similar; in addition, it provides an editor for specifying the to-be diagrams.

5.4 Exercise Example

In the following, a short exercise example applying *refacTutor* is illustrated in detail. In particular, the source code, runtime tests, the task to be performed by the user and the corresponding as-is and to-be design diagrams are presented.

Source Code. For this exemplary exercise, the following Java code fragment (containing basic classes and functionality for a simple banking application) has been prepared by the instructor (see Listing 2 and also the editor ④ in Fig. 9).


Home
Task Description
Source Code
Design Diagrams
①
Test Case 1
Test Case 2
Test Case 3
Test Case 4
②
Console output
③
Task 1
Task 2
Clear task
BankAccount.java
BankDeposit.java
④
Run Test
⑤
To-be design
Class Diagram
Sequence Diagram
⑥
Transaction
private BankAccount sender
private BankAccount receiver
public Transaction(BankAccount,BankAccount)
public Boolean transfer(Double)
sender
receiver
BankAccount
private Integer number
private Double balance
private Limit limit
public BankAccount(Integer,Double)
public Integer getNumber()
public Double getBalance()
public void increase(Double)
public void decrease(Double)
limit
Limit
private Double amount
public Double getAmount()
CheckingAccount
public CheckingAccount(Integer,Double)
As-is design
Class Diagram
Sequence Diagram
⑦
Transaction
public Boolean transfer(Integer,Integer,Double)
BankAccount
private Integer number
private Double balance
private Limit limit
public BankAccount(Integer,Double)
public Integer getNumber()
public Double getBalance()
public void increase(Double)
public void decrease(Double)
limit
Limit
private Double amount
public Double getAmount()

```
Modify the given code example so that all tests pass and the given design (as-is)
matches the targeted design (to-be).

In particular, this includes the following modifications:

Modify class "Transaction" according to the following aspects
- Add attributes "sender" and "receiver" both typed by class "BankAccount"
- Add a parametrized constructor with parameters "sender" and "receiver".
- Modify method transfer to only comprise one parameter ("amount").

Add a class "CheckingAccount", which should by a subclass of "BankAccount".
```

```
 @test
public void transfer_default() {
  BankAccount accountS = new BankAccount(00234573201, 2000.00);
  BankAccount accountR = new BankAccount(00173948725, 1500.00);
  Transaction trans = new Transaction (accountS, accountR);
  assertTrue(trans.transfer(300.00));
  assertEquals(accountS.getBalance(),1700);
  assertEquals(accountR.getBalance(),1800);
}
```

```
4 test cases were executed (0.264 s)
Test case 1 "transfer_default" failed.
Test case 2 "transfer_limitExceeded" failed.
Test case 3 "checkBalance_default" passed.
Test case 4 "accountConstructor_default" passed.
```

```
public class BankAccount {
  private Integer number;
  private Double balance;
  private Limit limit;

  public BankAccount(Integer number, Double balance) {
    this.number = number;
    this.balance = balance;
  }

  public Integer getNumber() {
    return this.number;
  }

  public Double getBalance() {
    return this.balance;
  }

  public void increase(Double amount) {
    this.balance += amount;
  }

  public void decrease(Double amount) {
    this.balance -= amount;
  }

}


public class Limit {
  private Double amount;

  public Double getAmount() {
    return this.amount;
  }

}
public class Transaction {

  public Boolean transfer(Integer senderNumber, Integer receiverNumber, Double amou
    BankAccount sender = new BankAccount(123456,2000.00);
    BankAccount receiver = new BankAccount(234567,150.00);
    if(sender.getBalance() >= amount){
      receiver.increase(amount);
      sender.decrease(amount);
    return true;
    } else {
      return false;
    }
  }

}
```

Figure 9: Screenshot of user's perspective with views provided by the *refacTutor* prototype implementation.

Listing 2: Java source code.

```
public class BankAccount {
  private Integer number;
  private Double balance;
  private Limit limit;
  public BankAccount(Integer number, Double balance) {
    this.number = number;
    this.balance = balance;
  }
  public Integer getNumber() {
    return this.number;
  }
  public Double getBalance() {
    return this.balance;
  }
  public void increase(Double amount) {
    this.balance += amount;
  }
  public void decrease(Double amount) {
    this.balance -= amount;
  }
}
public class Limit {
  private Double amount;
  public Double getAmount() {
    return this.amount;
  }
}
public class Transaction {
  public Boolean transfer(Integer senderNumber, Integer receiverNumber, Double amount) {
    BankAccount sender = new BankAccount(123456,2000.00);
    BankAccount receiver = new BankAccount(234567,150.00);
    if(sender.getBalance() >= amount){
      receiver.increase(amount);
      sender.decrease(amount);
      return true;
    } else {return false;}
  }
}
```

Tests. In this example, four *JUnit* test cases have been specified by the instructor (see Listing 3 and also the views ② and ③ in Fig. 9). Two out of these cases fail at the beginning (S_{INITIAL}).

Listing 3: Test result.

```
4 test cases were executed (0.264 s)
Test case 1 "transfer_default" failed.
Test case 2 "transfer_limitExceeded" failed.
Test case 3 "checkBalance_default" passed.
Test case 4 "accountConstructor_default" passed.
```

One of these failing cases is *transfer_default*, which is specified in the script in Listing 4.

Listing 4: Test case 1 *transfer_default*.

```
@test
public void transfer_default() {
  BankAccount accountS = new BankAccount(00234573201, 2000.00);
  BankAccount accountR = new BankAccount(00173948725, 1500.00);
  Transaction trans = new Transaction (accountS, accountR);
  assertTrue(trans.transfer(300.00));
  assertEquals(accountS.getBalance(),1700);
  assertEquals(accountR.getBalance(),1800);
}
```

Task. For the exercises, the user is confronted with the task presented in Listing 5 (also see ① in Fig. 9).

Listing 5: Task description.

```
Modify the given code example so that all tests pass and the given design (as-is) matches the targeted design (to-be).
In particular, this includes the following modifications:
(1) Modify class "Transaction" according to the following aspects
  (a) Add attributes "sender" and "receiver" both typed by class "BankAccount" to class "Transaction".
  (b) Add a parametrized constructor with parameters "sender" and "receiver".
  (c) Modify method transfer to only comprise one parameter ("amount" of type Double).
(2) Add a class "CheckingAccount", which should be a subclass of "BankAccount".
```

Design Diagrams. In the course of the exercise (after each code modification), the user can review the diagrams reflecting the actual design derived from code and compare them with the targeted design diagrams (see Fig.10; also see ⑥ and ⑦ in Fig. 9).

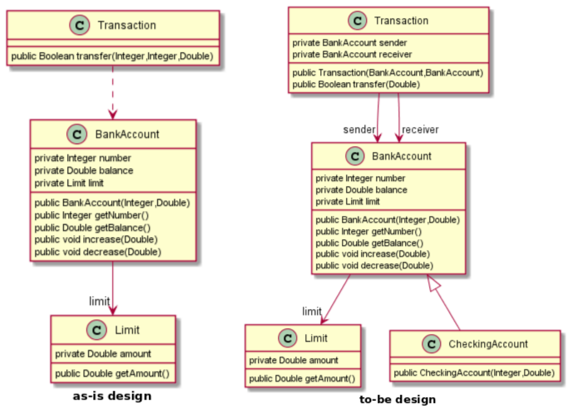

Transaction
public Boolean transfer(Integer,Integer,Double)
BankAccount
private Integer number
private Double balance
private Limit limit
public BankAccount(Integer,Double)
public Integer getNumber()
public Double getBalance()
public void increase(Double)
public void decrease(Double)
limit
Limit
private Double amount
public Double getAmount()
as-is design
Transaction
private BankAccount sender
private BankAccount receiver
public Transaction(BankAccount,BankAccount)
public Boolean transfer(Double)
sender
receiver
BankAccount
private Integer number
private Double balance
private Limit limit
public BankAccount(Integer,Double)
public Integer getNumber()
public Double getBalance()
public void increase(Double)
public void decrease(Double)
limit
Limit
private Double amount
public Double getAmount()
CheckingAccount
public CheckingAccount(Integer,Double)
to-be design

Figure 10: Contrasting as-is (automatically derived from source code; left-hand side) and to-be software design (targeted design specified by the instructor; right-hand side) both represented as UML class diagrams.

6 RELATED WORK

Related work can be roughly divided into the following two groups: (1) interactive tutoring systems for programming, especially those leveraging program visualization (in terms of UML diagrams) and (2) approaches for teaching refactoring, especially with focus on software design.

6.1 Tutoring Systems for Programming

Interactive learning environments in terms of editor-based web-applications such as *Codecademy* (Sims and Bubinski, 2018) are popular nowadays for learning programming. These tutoring systems provide learning paths for accomplishing practical competences in selected programming aspects. They motivate learners via rewards and document the achieved learning progress. Only very few tutoring systems can be identified that address software refactoring; see, e.g. (Sandalski et al., 2011). In particular, Sandalski et al. present an analysis assistant that provides intelligent decision-support and feedback very similar to a refactoring recommendation system, see, e.g. (Tsantalis et al., 2008). It identifies and highlights simple code-smell candidates. After the user's code modification, it reacts by proposing (better) refactoring options.

Related are also tutoring environments that present immediate feedback in terms of code and design visualization; for an overview, see, e.g. (Sorva et al., 2013). Only a few of these approaches provide the reverse-engineering of UML diagrams, such as *JAVAVIS* (Oechsle and Schmitt, 2002) or *BlueJ* (Kölling et al., 2003). However, existing approaches do not target refactoring exercises. For instance, they not allow for comparing the actual design (*as-is*) and the targeted design (*to-be*), e.g. as defined by the instructor, especially not in terms of UML class diagrams. Moreover, tutoring systems barely provide integrated software-behavior evaluation in terms of regression tests (pre-specified by the instructor).

We complement these approaches by presenting an approach that integrates immediate feedback on code modifications in terms of software-design quality and software behavior.

6.2 Approaches for Teaching Refactoring

Besides tutoring systems (discussed above) other kinds of teaching refactoring are related to our approach. In addition to tutoring systems based on instructional learning design, a few other learning approaches in terms of editor-based refactoring games can be identified that also integrate automated feedback. In contrast to tutoring systems which normally apply small examples, serious games such as (Elezi et al., 2016; Haendler and Neumann, 2019) are based on real-world code base. These approaches also include means for rewarding successful refactorings by increasing the game score (or reducing the technical-debt score) and partially provide competitive and/or collaborative game variants. However, so far these games do not include visual feedback that is particularly important for the training of design-related refactoring.

Moreover other approaches without integrated automated feedback are established. For instance, Smith et al. propose an incremental approach for teaching different refactoring types on college level in terms of learning lessons (Smith et al., 2006; Stoecklin et al., 2007). The tasks are also designed in an instructional way with exemplary solutions that have to be transferred to the current synthetic refactoring candidate (i.e. code smell). Within this, they provide an exemplary learning path for refactorings. Furthermore, Abid et al. conducted an experiment for contrasting two students groups, of which one performed *pre-enhancement* (refactoring first, then code extension) and the second *post-enhancement* (code extension first, then refactoring) (Abid et al., 2015).

Then they compared the quality of the resulting code. López et al. report on a study for teaching refactoring (López et al., 2014). They propose exemplary refactoring task categories and classify them according to Bloom's taxonomy and learning types. They also describe learning settings, which aim at simulating real-world conditions by providing, e.g. an IDE and revision control systems.

In addition to these teaching and training approaches, we present a tutoring system that can be seen as a link in the learning path between lectures and lessons (that mediate basic knowledge on refactoring) on the one hand and environments such as serious games that already demand practical competences on the other.

7 DISCUSSION

In this paper, a new approach has been presented for teaching and training practical competences in software refactoring. As shown above (Section 6), the tutoring system is considered as complement to other training environments and techniques, such as lectures for mediating basic understanding (before) and serious games (afterwards) for consolidating and extending the practical competences in direction of higher-level competences such as evaluating refactoring options and developing refactoring strategies. The provided decision support in terms of UML design diagrams (representing the *as-is* and *to-be* software design) especially addresses the refactoring of quality issues on the level of software design and architecture, which are not directly visible by reviewing the source code alone; also see *architectural debt* (Kruchten et al., 2012).

The feasibility of the proposed approach has been illustrated in two respects. On the one hand, in terms of the usability for training practical competences in software refactoring via two exemplary application scenarios, i.e. design refactoring and test-driven development, for which both the exercise workflows and other aspects have been described. On the other hand, by demonstrating the technical feasibility via a proof-of-concept implementation in Java that realizes the core functions. In this course, also a more detailed exercise example has been presented.

As a next step, it is necessary to investigate the appropriateness of the approach in an actual training setting (empirical evaluation) and gather feedback from system users. From a didactic perspective, a challenge in creating a training unit is to put together a set of appropriate refactoring exercises consisting of code fragments that manifest as smells in corresponding UML diagrams. An orientation for this can be seen in rules and techniques for identifying and refactoring smells on the level of software design (Suryanarayana et al., 2014). In addition, in (Haendler, 2018) we explored how 14 kinds of software-design smells can be identified (and represented) in UML class and sequence diagrams. This catalog can serve as a systematic guideline for creating exercises targeted on different design smells. For applying the prototype in a training setting, also further technical extensions and refinements are planned; for example, by including views for assessment and progress management (e.g. gamification elements such as leaderboards or activity charts).

8 CONCLUSION

In this paper, we presented a novel approach for teaching software refactoring, especially with focus software design issues, via an interactive development and learning environment that provides feedback to the user in terms of reverse-engineered UML diagrams, test behavior and an extensible array of quality aspects. The paper contributes to the state-of-the-art via the following aspects; by:

- presenting a *training environment* that supports users, e.g. university students or (more) experienced software developers, in accomplishing practical competences for software refactoring.
- illustrating exemplary *application scenarios* that show the feasibility of the approach for training practical competences in refactoring and test-driven development.
- providing a web-based software-technical implementation in Java (*refacTutor*) as *proof-of-concept* that demonstrates the technical feasibility of the proposed approach. Here also a short exercise example is illustrated in detail.
- specifying a generic concept and a *lightweight architecture* that integrates already existing analysis tools such as test frameworks, diagram editors (and quality analyzers), which allows one to implement the tutoring system for other programming languages as well.

As already discussed in Section 7, in the next step an empirical evaluation of the prototype implementation will be done. For this purpose, it is planned to integrate a training unit on refactoring for design smells into a university course on software design and modeling. The key questions here are how the training via the tutoring system is perceived by the users and to what extent it supports in acquiring practical refactoring competences.

REFERENCES

Abid, S., Abdul Basit, H., and Arshad, N. (2015). Reflections on teaching refactoring: A tale of two projects. In *Proceedings of the 2015 ACM Conference on Innovation and Technology in Computer Science Education*, pages 225–230. ACM.

Ajax.org (2019). AceEditor. https://ace.c9.io/ [March 21, 2019].

Alves, N. S., Mendes, T. S., de Mendonça, M. G., Spínola, R. O., Shull, F., and Seaman, C. (2016). Identification and management of technical debt: A systematic mapping study. *Information and Software Technology*, 70:100–121.

Argyris, C. (1977). Double loop learning in organizations. *Harvard business review*, 55(5):115–125.

Arisholm, E., Briand, L. C., Hove, S. E., and Labiche, Y. (2006). The impact of UML documentation on software maintenance: An experimental evaluation. *IEEE Transactions on Software Engineering*, 32(6):365–381.

Beck, K. (2003). *Test-driven development: by example*. Addison-Wesley Professional.

Bloom, B. S. et al. (1956). Taxonomy of educational objectives. vol. 1: Cognitive domain. *New York: McKay*, pages 20–24.

Campbell, G. and Papapetrou, P. P. (2013). *SonarQube in action (In Action series)*. Manning Publications Co.

Cañas, J. J., Bajo, M. T., and Gonzalvo, P. (1994). Mental models and computer programming. *International Journal of Human-Computer Studies*, 40(5):795–811.

CoderGears (2018). JArchitect. [March 21, 2019].

Elezi, L., Sali, S., Demeyer, S., Murgia, A., and Pérez, J. (2016). A game of refactoring: Studying the impact of gamification in software refactoring. In *Proceedings of the Scientific Workshop Proceedings of XP2016*, page 23. ACM.

Fernandes, E., Oliveira, J., Vale, G., Paiva, T., and Figueiredo, E. (2016). A review-based comparative study of bad smell detection tools. In *Proceedings of the 20th International Conference on Evaluation and Assessment in Software Engineering*, page 18. ACM.

Fontana, F. A., Braione, P., and Zanoni, M. (2012). Automatic detection of bad smells in code: An experimental assessment. *J. Object Technology*, 11(2):5–1.

Fontana, F. A., Dietrich, J., Walter, B., Yamashita, A., and Zanoni, M. (2016). Antipattern and code smell false positives: Preliminary conceptualization and classification. In *Proc. of 23rd International Conference on Software Analysis, Evolution, and Reengineering (SANER 2016)*, volume 1, pages 609–613. IEEE.

Forman, I. R. and Forman, N. (2004). *Java Reflection in Action (In Action series)*. Manning Publications Co.

Fowler, M., Beck, K., Brant, J., Opdyke, W., and Roberts, D. (1999). *Refactoring: improving the design of existing code*. Addison-Wesley Professional.

Gamma, E., Beck, K., et al. (1999). JUnit: A cook's tour. *Java Report*, 4(5):27–38.

George, C. E. (2000). Experiences with novices: The importance of graphical representations in supporting mental models. In *Proc. of 12 th Workshop of the Psychology of Programming Interest Group (PPIG 2000)*, pages 33–44.

Haendler, T. (2018). On using UML diagrams to identify and assess software design smells. In *Proc. of the 13th International Conference on Software Technologies*, pages 413–421. SciTePress.

Haendler, T. and Frysak, J. (2018). Deconstructing the refactoring process from a problem-solving and decision-making perspective. In *Proc. of the 13th International Conference on Software Technologies*, pages 363–372. SciTePress.

Haendler, T. and Neumann, G. (2019). Serious refactoring games. In *Proc. of the 52nd Hawaii International Conference on System Sciences*, pages 7691–7700.

Haendler, T., Sobernig, S., and Strembeck, M. (2015). Deriving tailored UML interaction models from scenario-based runtime tests. In *International Conference on Software Technologies*, pages 326–348. Springer.

Haendler, T., Sobernig, S., and Strembeck, M. (2017). Towards triaging code-smell candidates via runtime scenarios and method-call dependencies. In *Proceedings of the XP2017 Scientific Workshops*, pages 8:1–9. ACM.

IMS Global Consortium (2003). IMS simple sequencing best practice and implementation guide. *Final specification, March.*

Kölling, M., Quig, B., Patterson, A., and Rosenberg, J. (2003). The BlueJ system and its pedagogy. *Computer Science Education*, 13(4):249–268.

Kollmann, R., Selonen, P., Stroulia, E., Systa, T., and Zundorf, A. (2002). A study on the current state of the art in tool-supported UML-based static reverse engineering. In *Ninth Working Conference on Reverse Engineering, 2002. Proceedings.*, pages 22–32. IEEE.

Krathwohl, D. R. (2002). A revision of bloom's taxonomy: An overview. *Theory into practice*, 41(4):212–218.

Kruchten, P., Nord, R. L., and Ozkaya, I. (2012). Technical debt: From metaphor to theory and practice. *IEEE software*, 29(6):18–21.

Kruchten, P. B. (1995). The 4+1 view model of architecture. *IEEE software*, 12(6):42–50.

López, C., Alonso, J. M., Marticorena, R., and Maudes, J. M. (2014). Design of e-activities for the learning of code refactoring tasks. In *Computers in Education (SIIE), 2014 International Symposium on*, pages 35–40. IEEE.

Martini, A., Bosch, J., and Chaudron, M. (2014). Architecture technical debt: Understanding causes and a qualitative model. In *2014 40th EUROMICRO Conference on Software Engineering and Advanced Applications*, pages 85–92. IEEE.

Moha, N., Gueheneuc, Y.-G., Duchien, L., and Le Meur, A.-F. (2010). Decor: A method for the specification and detection of code and design smells. *IEEE Transactions on Software Engineering*, 36(1):20–36.

Mugridge, R. (2003). Challenges in teaching test driven development. In *International Conference on Extreme Programming and Agile Processes in Software Engineering*, pages 410–413. Springer.

Nord, R. L., Ozkaya, I., Kruchten, P., and Gonzalez-Rojas, M. (2012). In search of a metric for managing architectural technical debt. In *2012 Joint Working IEEE/IFIP Conference on Software Architecture and European Conference on Software Architecture*, pages 91–100. IEEE.

Object Management Group (2015). Unified Modeling Language (UML), Superstructure, Version 2.5.0. http://www.omg.org/spec/UML/2.5 [March 21, 2019].

Oechsle, R. and Schmitt, T. (2002). JavaVis: Automatic program visualization with object and sequence diagrams using the java debug interface (JDI). In *Software visualization*, pages 176–190. Springer.

Opdyke, W. F. (1992). *Refactoring object-oriented frameworks*. University of Illinois at Urbana-Champaign Champaign, IL, USA.

Parnas, D. L. (1994). Software aging. In *Proceedings of 16th International Conference on Software Engineering*, pages 279–287. IEEE.

Richner, T. and Ducasse, S. (1999). Recovering high-level views of object-oriented applications from static and dynamic information. In *Proceedings of the IEEE International Conference on Software Maintenance*, pages 13–22. IEEE Computer Society.

Roques, A. (2017). PlantUml: UML diagram editor. https://plantuml.com/ [March 21, 2019].

Sandalski, M., Stoyanova-Doycheva, A., Popchev, I., and Stoyanov, S. (2011). Development of a refactoring learning environment. *Cybernetics and Information Technologies (CIT)*, 11(2).

Scanniello, G., Gravino, C., Genero, M., Cruz-Lemus, J. A., Tortora, G., Risi, M., and Dodero, G. (2018). Do software models based on the UML aid in source-code comprehensibility? Aggregating evidence from 12 controlled experiments. *Empirical Software Engineering*, 23(5):2695–2733.

Sims, Z. and Bubinski, C. (2018). Codecademy. http://www.codecademy.com [March 21, 2019].

Smith, S., Stoecklin, S., and Serino, C. (2006). An innovative approach to teaching refactoring. In *ACM SIGCSE Bulletin*, volume 38, pages 349–353. ACM.

Sorva, J., Karavirta, V., and Malmi, L. (2013). A review of generic program visualization systems for introductory programming education. *ACM Transactions on Computing Education (TOCE)*, 13(4):15.

Stoecklin, S., Smith, S., and Serino, C. (2007). Teaching students to build well formed object-oriented methods through refactoring. *ACM SIGCSE Bulletin*, 39(1):145–149.

Suryanarayana, G., Samarthyam, G., and Sharma, T. (2014). *Refactoring for software design smells: Managing technical debt*. Morgan Kaufmann.

Tempero, E., Gorschek, T., and Angelis, L. (2017). Barriers to refactoring. *Communications of the ACM*, 60(10):54–61.

Trung, N. K. (2017). InMemoryJavaCompiler. https://github.com/trung/InMemoryJavaCompiler [March 21, 2019].

Tsantalis, N., Chaikalis, T., and Chatzigeorgiou, A. (2008). JDeodorant: Identification and removal of type-checking bad smells. In *12th European Conference on Software Maintenance and Reengineering (CSMR 2008)*, pages 329–331. IEEE.