### **Bachelor Project**



Czech
Technical
University
in Prague

F3

Faculty of Electrical Engineering
Department of Computer Graphics and Interaction

# Optimizing the Learning Environment in the I3T Tool for Different User Types

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Bachelor's thesis title in English:

Optimizing the Learning Environment in the I3T Tool for Different User Types

Bachelor's thesis title in Czech:

Optimalizace výukového prostředí v nástroji I3T pro různé typy uživatelů

### Guidelines:

The aim of the thesis is to improve the effectiveness of education using the Interactive Tool for Teaching Transformations (I3T), which is being developed at the department.

- Analyze the current state of the tool (existing scenes, tutorials, how to use it in teaching, manual, etc.).
- Identify key gaps in the current system, especially in the area of understandability and usability of tutorials and other teaching materials.
- Suggest changes for better use of the application by different types of users (e.g. beginners and advanced, lecturers, trainers, students at school, students at home, professional game programmers).
- Link the application to the manual on the website.
- Test the proposed changes with users.
- Based on the test results, make adjustments to the application so that it is better prepared for use in teaching and practice.
- Discuss the resulting solution and suggest steps for further development.

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### **DECLARATION**

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declare that I have elaborated the bachelor's thesis entitled

Optimizing the Learning Environment in the I3T Tool for Different User Types

independently, and have cited all information sources used in accordance with the Methodological Instruction on the Observance of Ethical Principles in the Preparation of University Theses and with the Framework Rules for the Use of Artificial Intelligence at CTU for Academic and Pedagogical Purposes in Bachelor's and Continuing Master's Programmes.

I declare that I used artificial intelligence tools during the preparation and writing of this thesis. I verified the generated content. I hereby confirm that I am aware of the fact that I am fully responsible for the contents of the thesis.

In Prague on 17.05.2025	Karolína Zapletalová
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I am grateful to my family, especially my mother and father, for always believing in me, supporting my choices, and encouraging me to pursue what I enjoy. Their emotional support, understanding, and practical help were what kept me going, and I would not have managed without them.

Finally, I would like to thank my partner and my closest friends, those who stood by my side, pushed me forward, and also reminded me to take breaks. Whether it was taking me out, playing games, or watching movies, I truly appreciate every moment. Thank you to the old friends who have stayed with me over the years and to the new ones I was lucky to meet thanks to my studies.

# **Declaration**

I have elaborated the bachelor's thesis entitled Optimizing the Learning Environment in the I3T Tool for Different User Types independently, and have cited all information sources used in accordance with the Methodological Instruction on the Observance of Ethical Principles in the Preparation of University Theses and with the Framework Rules for the Use of Artificial Intelligence at CTU for Academic and Pedagogical Purposes in Bachelor's and Continuing Master's Programmes.

I declare that I used artificial intelligence tools during the preparation and writing of this thesis. I verified the generated content. I hereby confirm that I am aware of the fact that I am fully responsible for the contents of the thesis.

### **Abstract**

This thesis explores ways to improve the Interactive Tool for Teaching Transformations (I3T), an educational application used for teaching 3D transformations. The focus is on enhancing its tutorials, manual, classroom integration, and user onboarding to better support students, teachers, and other user groups.

The work includes an analysis of the tool, definition of typical user roles, design of new teaching materials, and evaluation through classroom use.

As part of this work, the manual was restructured and tested in real classroom settings with over 80 students. During the evaluation, 83% of students rated the tutorials as easy to understand but pointed out lack of theoretical integration and missing verification/feedback mechanisms. Over 90% reported improved comprehension of transformation concepts. Feedback helped identify areas for improvement and guided the redesign of learning materials and user interface components. Based on the findings, a new tutorial was created and the welcome window was redesigned.

The thesis also outlines suggestions for future development, such as tutorial progress tracking and better support for teaching workflows.

**Keywords:** I3T, educational tools, 3D transformations, usability testing, user-centered design, tutorials

**Supervisor:** Ing. Petr Felkel, Ph.D.

### **Abstrakt**

Práce se zabývá zlepšením nástroje I3T (Interactive Tool for Teaching Transformations), vzdělávací aplikace určené k výuce 3D transformací. Cílem je vylepšit její tutoriály, manuál, začlenění do výuky a úvodní rozhraní tak, aby lépe vyhovovala potřebám studentů, vyučujících a dalších uživatelů.

Součástí práce je analýza nástroje, definice typických uživatelských rolí, návrh nových výukových materiálů a ověření použití aplikace v rámci výuky.

V rámci práce byl přepracován manuál a otestován přímo v hodinách s více než 80 studenty. Během evaluace označilo 83% studentů tutoriály za snadno pochopitelné, ale upozornili na nedostatečné propojení s teorií a chybějící ověřování nebo zpětnou vazbu. Více než 90% uvedlo, že jim nástroj pomohl lépe pochopit principy transformací. Zpětná vazba pomohla identifikovat slabá místa a nasměrovala úpravy výukových materiálů i uživatelského rozhraní. Na základě těchto zjištění byl vytvořen nový tutoriál a přepracováno úvodní okno aplikace.

Práce rovněž navrhuje další rozvoj, například ukládání postupu v tutoriálech nebo lepší podporu výuky v hodinách.

Klíčová slova: I3T, vzdělávací nástroje, 3D transformace, uživatelské testování, návrh zaměřený na uživatele, tutoriály

**Překlad názvu:** Optimalizace vzdělávacího prostředí v nástroji I3T pro různé typy uživatelů

# Contents

1 Introduction	1
1.1 Objectives	1
1.2 Background and Motivation	$\overline{2}$
_	3
2 Theoretical Background	_
2.1 Learning Theories and Educationa Materials	
	3
2.2 User-Centered Design	4
2.3 Insights from Educational Tools and Games	4
	4
3 Analysis of the Deployed I3T	
System	7
3.1 Overview of the System	7
3.2 Identified Gaps and Issues	8
3.2.1 Tutorials	9
3.2.2 Manual	13
3.2.3 Welcome Window	14
4 User Needs and Role-Based	
Archetypes	17
4.1 Beginners	18
4.2 Advanced Users	18
4.3 Teachers	19
4.4 Students	19
4.5 Focus Areas	20
5 Manual: Development	21
5.1 Changes to the Manual	21
6 Teaching Scenarios	27
6.1 Evaluation of the Teaching Path	27
6.2 Preparation of Two Week Teaching	
Scenarios	28
6.2.1 First Week and Basics	29
6.2.2 Second Week and Advanced	
Topics	29
6.2.3 Final Practice Session and	
Testing Quiz	30
6.2.4 Competition	
6.2.5 Evaluation Design	30
	30 30
9	
6.3 User Testing	30
6.3 User Testing	30 31
6.3 User Testing	30 31 31
6.3 User Testing	30 31 31
6.3 User Testing	30 31 31 31

	33
6.4.1 Quiz Observations	33
6.4.2 Quantitative Knowledge	
Testing	34
6.4.3 Feedback	35
6.4.4 Comparative Analysis of	
Student Groups	39
7 Improvements Made and Ideas Fo	r
Future Development	41
7.1 Manual	41
7.1.1 Implementation	41
7.1.2 Proposals	42
7.2 Tutorials	42
7.2.1 Implementation	43
7.2.2 Proposals	43
7.3 Welcome Window	44
7.3.1 Implementation	44
7.3.2 Proposals	45
7.4 Teaching Framework	46
8 Conclusion	49
References	51
A List of Abbreviations	55
B Used Software	57
B Used Software C Attached files	
C Attached files	57
	57 59
C Attached files C.1 Old Manual	<b>57 59</b> 59
C Attached files C.1 Old Manual	<b>57 59</b> 59
C Attached files C.1 Old Manual	<b>57 59</b> 59 59 59
C Attached files C.1 Old Manual	<b>57 59</b> 59 59
C Attached files C.1 Old Manual	57 59 59 59 59 61
C Attached files C.1 Old Manual	577 599 599 599 599 61
C Attached files C.1 Old Manual C.2 New Manual C.3 New Introductory Tutorial C.4 Class Scenario D Quizzes and Questionnaires D.1 First Week Quiz D.1.1 Questions	57 59 59 59 59 61 61
C Attached files C.1 Old Manual	57 59 59 59 59 61 61 62
C Attached files C.1 Old Manual C.2 New Manual C.3 New Introductory Tutorial C.4 Class Scenario  D Quizzes and Questionnaires D.1 First Week Quiz D.1.1 Questions D.1.2 Correct Answers D.2 Second Week Quiz	577 599 599 599 611 611 622 633
C Attached files C.1 Old Manual C.2 New Manual C.3 New Introductory Tutorial C.4 Class Scenario  D Quizzes and Questionnaires D.1 First Week Quiz D.1.1 Questions D.1.2 Correct Answers D.2 Second Week Quiz D.2.1 Questions D.2.2 Correct Answers D.3 Comprehensive Final Quiz	577 599 599 599 599 611 611 622 633
C Attached files C.1 Old Manual C.2 New Manual C.3 New Introductory Tutorial C.4 Class Scenario  D Quizzes and Questionnaires D.1 First Week Quiz D.1.1 Questions D.1.2 Correct Answers D.2 Second Week Quiz D.2.1 Questions D.2.2 Correct Answers D.3 Comprehensive Final Quiz D.3.1 Questions	577 599 599 599 599 611 611 622 633 634 644
C Attached files C.1 Old Manual C.2 New Manual C.3 New Introductory Tutorial C.4 Class Scenario  D Quizzes and Questionnaires D.1 First Week Quiz D.1.1 Questions D.1.2 Correct Answers D.2 Second Week Quiz D.2.1 Questions D.2.2 Correct Answers D.3 Comprehensive Final Quiz D.3.1 Questions D.3.2 Correct Answers	57 59 59 59 59 61 61 62 63 63 64 64 64
C Attached files C.1 Old Manual C.2 New Manual C.3 New Introductory Tutorial C.4 Class Scenario  D Quizzes and Questionnaires D.1 First Week Quiz D.1.1 Questions D.1.2 Correct Answers D.2 Second Week Quiz D.2.1 Questions D.2.2 Correct Answers D.3 Comprehensive Final Quiz D.3.1 Questions D.3.2 Correct Answers D.4 Feedback Questionnares	57 59 59 59 59 61 61 62 63 63 64 64 65 65
C Attached files C.1 Old Manual C.2 New Manual C.3 New Introductory Tutorial C.4 Class Scenario  D Quizzes and Questionnaires D.1 First Week Quiz D.1.1 Questions D.1.2 Correct Answers D.2 Second Week Quiz D.2.1 Questions D.2.2 Correct Answers D.3 Comprehensive Final Quiz D.3.1 Questions D.3.2 Correct Answers D.4 Feedback Questionnares D.4 Feedback Questionnares D.4.1 First Week Feedback	57 59 59 59 59 61 61 62 63 63 64 64 65 65
C Attached files C.1 Old Manual C.2 New Manual C.3 New Introductory Tutorial C.4 Class Scenario  D Quizzes and Questionnaires D.1 First Week Quiz D.1.1 Questions D.1.2 Correct Answers D.2 Second Week Quiz D.2.1 Questions D.2.2 Correct Answers D.3 Comprehensive Final Quiz D.3.1 Questions D.3.2 Correct Answers D.4 Feedback Questionnares	57 59 59 59 59 61 61 62 63 63 64 64 65 65

# Figures |

3.1 Original Manual	13
3.2 Original welcome window layout.	15
5.1 Collapsible structure used in the	
Camera and Screen section	22
5.2 Screenshot from the manual	
showing matrix operations in a node	
graph	22
5.3 Screenshot of a GIF from the	
manual demonstrating matrix input	
methods	23
5.4 Section of the manual showing the	
Start Window layout	23
5.5 Manual content illustrating node	
setup and transformation logic in the	
workspace	
5.6 Scene view documentation showing	•
manipulators	24
6.1 Ratings of how easy the tutorials	
were to understand (All students).	36
6.2 Percentage of "Yes" answers to	
questions about tutorials	36
6.3 Percentage of "Yes" answers to	
questions about manual	37
6.4 Distribution of FEL and FIT	
students across all quizzes	39
7.1 Design sketches with proposed	
improvements	45
7.2 Implemented welcome window	
showing the new Recent section and	
headers	46

# **Tables**

6.1 Correct and Partial Answers by
Group and Question (Comprehensive
Test)
6.2 Cumulative Feedback Ratings from
All Students (n=78) 37

# Chapter 1

# Introduction

The Interactive Tool for Teaching Transformations (I3T) is a node-based educational application used in teaching 3D transformations. This thesis explores how to improve its learning materials, user interface, and integration into classroom teaching. Building upon previous development efforts, it identifies usability and instructional gaps and proposes design changes that are evaluated through structured classroom testing.

# 1.1 Objectives

The aim of this thesis is to improve the educational effectiveness of the Interactive Tool for Teaching Transformations (I3T), developed at the Department of Computer Graphics and Interaction. The focus lies on enhancing the tool's tutorials, manual, and onboarding interface, and on integrating it more effectively into classroom teaching. These improvements are designed to support the specific needs of diverse user groups.

The objectives of the thesis are to analyze the current state of the I3T tool, including its available scenes, tutorials, manual, and its role in teaching. A key goal is to identify usability and understandability gaps, particularly within tutorials and instructional materials, and furthermore propose design changes that support various user types, such as beginners, advanced users, teachers, and students in both classroom and self-study contexts. Another objective is to strengthen the connection between the application and its documentation by linking the manual more closely to the content in the app.

Because the original manual and classroom materials would not benefit from testing in their prior state, they first need to be revised based on the analysis. The objective of the evaluation is to assess these revised components through structured classroom use involving students. The testing is intended to include

1. Introduction

different methods of evaluation, such as theoretical quizzes, practical tasks, and structured feedback collection. The results should provide insight into the usability, clarity, and educational value of the tool.

By addressing the identified gaps, the thesis seeks to create a more engaging and accessible learning environment that better supports educational goals.

### 1.2 Background and Motivation

I3T is an educational tool designed to teach 3D transformations in computer graphics. It enables users to build visual scenes using a node-based interface and observe the effects of transformation matrices and camera operations in real time. The tool has been integrated into the teaching of computer graphics at the Faculty of Electrical Engineering, where it complements traditional lectures by visualizing abstract mathematical concepts.

The original version of I3T was created in 2016 by Michal Folta [1] as part of a master's thesis. It introduced the core concept of combining a 2D workspace editor for transformation matrices with a 3D viewport for immediate feedback. Although the tool became an important aid in the course PGR, the early versions suffered from outdated design, inconsistent usability, and limited functionality.

In 2020, a complete redesign of the application began, supported by contributions from multiple student projects. In particular, Adam Loucký [2] focused on improving the onboarding experience by designing and implementing a structured tutorial system to guide users through key features and concepts of the application.

Despite these advancements, the application remained in an in-progress state and was not fully usable as a standard educational tool. Key problems included gaps in theoretical support within tutorials, lack of a structured and accessible manual, and the absence of teaching scenarios. Addressing these issues is necessary for broader classroom adoption.

# Chapter 2

# **Theoretical Background**

This chapter establishes the theoretical foundation for optimizing interactive learning environments by examining three key areas: learning theories relevant to technical education, principles of user-centered design (UCD) for educational tools, and best practices from successful educational games and visualization systems.

# 2.1 Learning Theories and Educational Materials

Learning in technical fields such as computer graphics often involves understanding abstract concepts that are difficult to visualize without specialized support. Learning approaches therefore play a central role. According to Taxén [3], constructive teaching emphasizes active engagement, where learners build understanding through exploration, experimentation, and reflection rather than passive absorption of information.

The effectiveness of educational tools depends not only on the delivery of content, but also on how learners interact with the materials. Moradi et al. [4] demonstrated that problem-based learning environments integrated with serious games can significantly improve the comprehension of 3D computer graphics concepts, particularly when tasks require the application of prior knowledge to complete visual and interactive challenges. Their findings align with research highlighting that combining theoretical knowledge with immediate feedback and practical application fosters deeper learning [5].

Self-assessment is another core principle that supports learning in exploratory environments. When learners can assess their progress and identify misconceptions through in-tool cues or outcome comparisons, understanding becomes more robust. The ability to compare expected and observed results enables users to internalize transformation logic through iterative correction

and experimentation.

Gamification principles have also shown value in promoting motivation and sustained engagement. Deterding et al. [6] define gamification as the use of game design elements in non-game contexts to enhance user experience and engagement. As demonstrated in the development of the GTCards game by González-Campos et al. [7], integrating gameplay mechanics can help reinforce concepts without undermining the seriousness of the subject matter. However, these techniques must be applied judiciously to support, rather than distract from, core learning goals.

Effective educational materials not only explain but also provide structure, motivation, feedback, and opportunities for active engagement.

### 2.2 User-Centered Design

Interactive educational tools are most effective when they align with the needs, skills, and expectations of their users. User-centered design (UCD), as formalized in ISO 9241-210 [8], defines a structured process for developing systems that prioritize usability and user experience from the earliest design stages. A core principle of UCD is early user involvement and iterative design [9]. This is particularly important in educational contexts where user roles differ substantially, for example, between students, educators, and advanced practitioners.

Bullinger et al. [10] argue that user-centered design is essential when developing highly interactive or immersive systems, as it ensures the system fits the cognitive and functional requirements of the user. This principle is applicable across educational tools, which must accommodate varied learning goals and interaction strategies.

Consistency and clarity across the interface are also critical. According to ISO 9241-110 [11], interaction principles such as predictability, self-descriptiveness, and error tolerance help reduce user frustration and facilitate task learning. Embedding these principles ensures that learners remain confident, engaged, and able to progress at their own pace.



# 2.3 Insights from Educational Tools and Games

Several insights from the design of educational tools and serious games contribute to effective interactive learning environments. Interactivity must go beyond superficial manipulation to promote meaningful engagement directly tied to learning objectives. When users manipulate objects or parameters,

they should observe immediate, interpretable consequences that reinforce conceptual understanding.

Feedback mechanisms are central to this process. Suselo et al. [12] found that learners struggle with 3D transformations when feedback is delayed, ambiguous, or disconnected from their actions. Real-time visual updates, accompanied by clear cues about system state and correctness, help learners build accurate mental models of spatial transformations.

Although gamification is not universally appropriate, it can improve motivation when used selectively and in alignment with instructional goals. Visual indicators of progress, unlockable challenges, and structured pathways for task completion have been shown to enhance engagement in learning environments [6, 7].

In summary, effective educational tools succeed not simply by presenting content but by structuring the learner's experience through interaction, feedback, and progressive challenges. These principles are particularly valuable in helping students master complex and abstract spatial concepts within technical education.

# Chapter 3

# Analysis of the Deployed I3T System

This chapter provides a comprehensive analysis of the state of I3T version v2.0.0-rc.4 from February 2025, focusing on its learning materials, usability, and adaptability for different types of users. The goal is to identify key gaps and issues that hinder the effectiveness of the tool as an educational resource. By examining the tutorials, the manual, and the welcome window, as well as the needs of various user personas, this analysis lays the groundwork for the proposed improvements discussed in later chapters.

# 3.1 Overview of the System

The current version of I3T is a functional tool designed to support the teaching and understanding of linear algebra and transformations in computer graphics. It allows users to interact with mathematical concepts in real time, enhancing their grasp of abstract topics like matrix operations and transformations.

The system includes several key components:

- Workspace: The workspace is a central part of the application, located by default in the bottom section of the interface. It serves as a 2D node editor, where users create and connect nodes that define the structure and logic of their scenes. Each node represents either a transformation, model, camera, or a mathematical operation such as matrix manipulation, vector arithmetic, or quaternion rotation. The overall structure and usability of the workspace are the focus of the bachelors thesis of Barbora Hálová [13], who is addressing its visual design and user interaction model.
- Scene View: The scene view displays a real-time rendering of the 3D scene constructed in the workspace. It allows users to immediately observe the effect of their transformations and camera setups. The scene view supports direct interaction, such as object manipulation and camera

movement, which helps reinforce the connection between abstract matrix operations and their visual outcomes. Dan Rakušan [14] is developing ongoing improvements to the usability and layout of this interface as part of his master thesis to refine the node representation and improve the integration between workspace and viewport.

- Tutorials: The tutorials guide users through the basic components and functionality of the application. They consist of a series of short instructional steps covering topics such as navigation, transformations, object manipulation, and camera. Each tutorial introduces a specific set of blocks and actions within the workspace. The original tutorial system was designed and implemented as part of the work of Adam Loucký [2], providing a valuable foundation for user onboarding. The content is primarily focused on demonstrating how to use the interface, its features and partially on theory about transformations.
- Manual: The manual provides a text-based reference for the application's features. It is organized into sections covering different interface elements, including the workspace, manipulators, and technical manual. Each section contains headings and short descriptions.
- Welcome Window: The welcome window appears upon launching the application and serves as the main entry point for users. It features a short description of the tool, a language selection option, and access to two primary sections: "Your Scene" for creating or opening projects, and "Tutorials" for guided walkthroughs. The layout is static, and all options are presented on a single screen.

I3T has been used in various teaching contexts at the Faculty of Electrical Engineering (FEL) and the Faculty of Information Technology (FIT), primarily in the PGR (Computer Graphics) course. It has supported lectures, self-study, and even efforts to replace traditional whiteboard instruction during practical classes.

# 3.2 Identified Gaps and Issues

The focus of this thesis is on the understandability of the (I3T) and its ability to support effective learning. The goal is to identify areas where the tool may confuse users, lack clarity, or make it difficult to grasp key transformation concepts. Although some of these issues relate to broader user experience (UX) design, this work considers only those problems that directly hinder comprehension, such as gaps in explanations, interface cues, or instructional flow.

### 3.2.1 Tutorials

The tutorials are a core feature designed to help users learn how to use the application. However, the analysis identified three major areas where they currently fall short: limited content coverage, lack of theoretical integration, and weak instructional structure. The limitations observed contrast with the principles described by Andersen et al. [15], who emphasize that well-structured tutorials and adaptive feedback mechanisms are essential for maintaining user engagement and supporting learning success, particularly in complex interactive environments. Furthermore, the application still relies heavily on teacher guidance and does not function as a fully self-sufficient teaching tool, which limits its effectiveness in self-study or exploratory learning scenarios.

First, the tutorials cover only a small portion of the application's key components. Several important elements, such as hierarchical transformations, operators, cycle, and frustum, are missing or not sufficiently explained.

Second, they do not integrate the theoretical context with the practical steps. Most tutorials focus solely on how to use specific blocks or functions without explaining the underlying mathematical principles. This makes it difficult for learners to connect visual actions with formal concepts, especially in areas like matrix composition or projection.

Third, the tutorials lack an instructional structure. There is no clear progression between tutorials and users do not receive feedback on whether tasks were completed correctly. Navigation is inconsistent, and some interface conventions, such as node connections or the difference between tips, recommendations and comments, are not introduced systematically.

These usability and learning challenges are examined in greater depth in the following subsection, which provides a structured, criteria-based analysis of each tutorial.

### Comprehensive Tutorial Analysis with Theoretical Framework

To deepen the assessment of tutorial usability, this subsection presents a detailed examination of I3T's tutorial system through the perspective of beginner users (the role-based archetype defined in Chapter 4). The analysis systematically evaluates how the tutorials introduce core concepts to learners with no prior experience in similar tools, focusing on aspects that may appear automatic to experienced users but create barriers for novices.

Three key criteria guide this evaluation: (1) the logical progression and sequencing of concepts, (2) explicit connections between theoretical foundations and practical applications, and (3) completeness of essential feature coverage.

These dimensions are particularly crucial for beginners, as established by Suselo and Wünsche's [16] research on 3D transformation learning curves and Moradi and Abdullah's [4] findings about novice cognitive load in problem-based environments. The ISO 9241-210 standard [8] further confirms that progressive disclosure of interface complexity significantly impacts first-time user success.

While this evaluation focuses on beginners, other user types—such as advanced users and teachers—may also encounter limitations in the tutorial system. These broader perspectives are discussed in the following chapter on user needs and archetypes (see Chapter 4).

### **Evaluation Criteria.**

The analysis employs three evidence-based criteria derived from literature and ISO standards to evaluate the tutorial system's effectiveness for beginner users:

Pedagogical Soundness evaluates how well tutorials integrate theory with practice, prevent errors, and scaffold learning. This draws on Taxén's [3] constructive learning principles and Suselo and Wünsche's [12] findings about 3D transformation challenges. Scaffolding, defined as guided support that enables learners to accomplish tasks they could not complete unaided, plays a key role in such learning designs [17]. Key metrics include the balance between conceptual explanations and practical tasks, presence of self-verification mechanisms, and logical progression of concepts.

Completeness assesses whether tutorials cover essential features and link to additional resources when needed. Grounded in ISO 9241-13's [18] user guidance standards, this examines whether all necessary components are present for building core competencies while avoiding information overload through thoughtful organization and progressive disclosure of complexity.

Consistency measures uniformity in design patterns across tutorials, including tip conventions, terminology, and task structures. This criterion applies ISO 9241-110's [11] interaction principles to evaluate whether interface elements behave predictably across different tutorials, maintaining coherent conventions that reduce cognitive load for beginners.

### **Tutorial 1: I3T Introduction.**

The tutorial's navigation instruction appears only on the second slide after users must already interact (Consistency), and focuses on tutorial components rather than movement between slides. While introducing key node types, it omits why they're essential (Pedagogical Soundness) and fails to link to the manual for extended learning (Completeness).

Critical information flows poorly - connections are demonstrated before explaining inputs, and node purposes are revealed after connection tasks rather than during introduction (Pedagogical Soundness). The summary falsely claims "learned basics" when users merely followed instructions without understanding core concepts like node relationships or matrix operations (Pedagogical Soundness).

### Tutorial 2: Working with transformations.

The tutorial provides only minimal theoretical context about transformations and homogeneous coordinates (Pedagogical Soundness), missing opportunities to link to detailed explanations in the manual (Completeness). Key concepts like matrix synergies appear mid-task without proper introduction, and the color-coding system (green/gray indicators) is explained only during scaling rather than established upfront (Consistency).

Critical learning moments are disrupted by scattered information flow, rotation principles appear separately from their matrix values, reset functionality is introduced late, and context menus are mixed with theory explanations (Pedagogical Soundness). The inconsistent tip presentation (written vs. clickto-open) further complicates the learning process for beginners (Consistency).

### **Tutorial 3: Composing transformations.**

The tutorial effectively uses practical tasks to demonstrate transformation composition (Pedagogical Soundness), but fails to explain why TRS order matters mathematically or why it is conventionally preferred (Pedagogical Soundness). While showing different ordering outcomes is valuable, the lack of theoretical justification creates another "why", particularly problematic when introducing hierarchical transformations later in the flow (Completeness).

The tracking visualization works well for demonstrating matrix effects (Pedagogical Soundness), but its introduction could better connect to the order of transformations. Though the final task provides an immediate reference image (helpful for verification), this risks encouraging blind copying rather than understanding, a missed opportunity for staged hints that would support genuine trial-and-error learning (Pedagogical Soundness).

### **Tutorial 4: Camera and Projections.**

The tutorial effectively introduces camera and screen nodes (Pedagogical Soundness), though it misses opportunities to link these advanced components to manual explanations (Completeness). Concepts like the PVM matrix and OpenGL connections appear without sufficient context. A wording issue makes view and lookAt matrices appear identical rather than related but distinct concepts (Pedagogical Soundness).

While demonstrating projection parameters practically, the tutorial would benefit from embedded mathematical explanations with links to supporting materials (Completeness). The unexplained mention of frustum creates a conceptual gap (Pedagogical Soundness), and though the orthographic versus perspective comparison is valuable, providing complete solution images may reduce opportunities for authentic problem-solving.

### **Tutorial 5: Additional I3T Features.**

The tutorial misleadingly labels basic efficiency tools like the top bar as "advanced" (Consistency), while important functions like operators receive only superficial coverage without practical examples (Completeness). Most content recycles previous tutorial material rather than properly introducing new concepts, with operators - which deserve dedicated explanation - compressed into a brief overview (Pedagogical Soundness).

### Tutorial 6: I3T Practical Recap.

This tutorial provides a concise, theory-free review of core functionalities (Pedagogical Soundness), serving different needs for different users: beginners can reinforce procedural knowledge, while advanced users gain quick access to forgotten features. However, it inherits the structural limitations of the original tutorials, including the absence of progress tracking, inconsistent navigation, and limited task verification—issues discussed in Section 3.2.1.

The purely practical approach works well as a memory aid (Pedagogical Soundness), particularly for students needing workflow reminders or experienced users wanting functionality overviews.

### Exercises.

In addition to the main tutorials, three optional exercises like Table, Detective and Scripting are available. Although not a central focus of this thesis, one of these exercises introduces the concept of enhancing scenes through custom scripting using the integrated Lua scripting interface. This feature allows users to create new node types or add interactive logic by writing small scripts directly within the application.

This particular exercise introduced three prototype scripts: a workspace-checking script used to verify whether required nodes had been placed correctly, and two additional scripts designed to enable simple quiz functionality within tutorial slides. All three scripts suffer from significant limitations, especially when users move back in the tutorial or delete key elements. These cases caused the scripts to fail or not be properly reset, making them unreliable and difficult to reuse in a teaching environment.

### 3.2.2 Manual

The manual is intended to provide users with a clear and reliable reference for understanding and operating the I3T application. However, analysis reveals that its current version fails to support diverse user needs and does not meet established standards for usability and instructional documentation. This section highlights specific deficiencies with reference to ISO guidance and minimalist design principles, which informed the subsequent redesign in Chapter 5. The shortcomings described below are visually evident in the original version of the manual, shown in Figure 3.1.

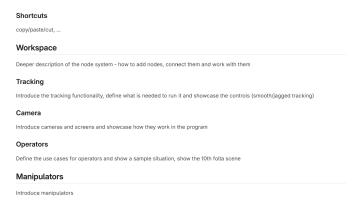


Figure 3.1: Original Manual.

- 1. Incomplete coverage and structure of content. The manual provides only a surface-level overview of key components. It contains no fully developed sections and includes only a few headings, each with a one-line description—for example, "Shortcuts," "Workspace," and "Manipulators." Some important sections are missing entirely, such as "Scene View," while others, like "Manipulators," are left without context or explanation. This falls short of the completeness principle in ISO 9241-13, which emphasizes the need for clear user guidance that supports core functionality, efficient information retrieval, and action-focused structure [18]. It also contradicts Lazonder and van der Meij's findings on the need for concise but sufficient documentation that helps users complete real tasks while filling in any gaps using context and examples [19].
- 2. Lack of support for different user reading strategies. According to van der Meij [20] and Carroll's Principle 4 [21], manuals should be organized to support different reading behaviors, with independent sections, visible prerequisites, and clear signals for navigation and learning. Users read manuals in various ways, some follow them step-by-step, others study concepts in depth, and many look up specific information as needed. The I3T manual fails to meet these expectations, making it harder for users to study, browse, or find help efficiently. It is not modular or clearly structured: entire sections like "Scene View" are missing, and many components appear in the wrong

place or without proper explanation. For those reading to study, the manual offers no theoretical context or links to supporting materials that would help users understand the underlying concepts—particularly important in areas like transformations or projections.

3. Missing visual and contextual guidance. Minimalist design recommends using simple visuals and interaction-based feedback instead of long blocks of explanation [20]. The I3T manual does not include screenshots, examples, or diagrams, which is a major problem in a tool designed around visual 3D concepts. This makes it harder for users—especially beginners unfamiliar with transformations—to understand how the interface works. Without visual support, the manual increases the mental effort required to learn the tool, which negatively affects usability as defined by the ISO 9241-11 learnability criterion [8].

Together, these issues render the manual ineffective as either an onboarding tool or a reference guide. The redesign presented in Chapter 5 builds on this critique by restructuring the manual into modular, navigable, and visually supported sections that incorporate minimalist principles such as brevity, progressive disclosure, and support for different user behaviors. The original version of the manual is available in Appendix C.1 for reference.

### 3.2.3 Welcome Window

The welcome window is the first screen presented to users upon launching the I3T application, yet its current implementation does not support effective onboarding or user re-engagement. As shown in Figure 3.2, the window consists of a static layout with minimal functionality and limited content structure.

One of the most immediate issues is the inconsistency in language usage. The introductory description remains fixed in English, while other interface elements may change language based on system settings or user preference, leading to a fragmented experience for non-English speakers. In addition, the layout lacks section headers or visual groupings, making it difficult to distinguish between scene controls and tutorial options.

Another major limitation is the lack of quick access to recently opened scenes. Unlike common design patterns found in tools like Blender or Visual Studio, I3T does not display recent files in the welcome screen. Instead, users must open scenes manually through the "File" menu, which adds friction to restarting work or continuing a task from a previous session. This omission is especially disruptive for returning users or teachers managing multiple scenes.

Lastly, the welcome screen does not provide any indication of user progress through the tutorials. All tutorials are presented uniformly, regardless of

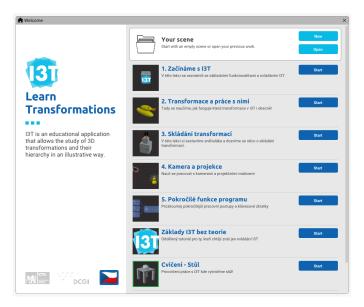


Figure 3.2: Original welcome window layout.

prior completion, reducing orientation.

Together, these issues make the welcome window ineffective as an entry point for new or returning users. The interface does not guide different types of user toward appropriate resources and does not reflect personalization patterns.

# Chapter 4

# **User Needs and Role-Based Archetypes**

Effective educational tools must be tailored to the diverse needs of their users. This chapter defines four role-based archetypes for I3T: beginner, advanced user, teacher, and student. The development of these archetypes is based on classroom observations and is informed by user-centered design (UCD) methodology, where understanding user goals and behaviors is key to designing effective systems [22].

Using personas to represent different types of users allows designers to create more empathetic and focused solutions, especially in educational contexts where users vary widely in background, expertise, and goals [23, 24]. Each archetype is linked to specific educational and interface needs, such as scaffolding for beginners, speed and precision for experts, or curriculum alignment for educators.

This approach supports design principles shown to enhance learning experiences, including interactive engagement, immediate feedback, and motivational elements such as gamification. As Gee argued, well-designed learning tools, such as effective games, provide challenges that are meaningful, progressively difficult, and embedded in contextual feedback [5]. When gamification is used intentionally and aligned with user goals, it can further boost engagement and motivation, particularly for self-guided learners [6].

The archetypes were created based on a combination of personal experience using I3T as a student and beginner, feedback from teachers, and informal conversations with classmates. Rather than being derived from formal testing, these profiles reflect recurring patterns observed in user needs and goals during actual classroom use. They were analytically formulated to capture the diversity of perspectives relevant to both learning and teaching with the tool.

The resulting archetypes served as a foundation for selecting appropriate features and instructional strategies throughout the design process. They

ensured that I3T would meet the distinct needs of its users and function effectively both as a learning tool and a practical reference in various educational settings.

# 4.1 Beginners

New users need clear, step-by-step instructions with visual aids to help them understand basic concepts and workflows. They benefit from real-time feed-back and task verification to ensure they are on the right track. Motivation is also important, and gamification elements like unlocking tutorials, earning badges, and gradually introducing features can help beginners stay engaged without feeling overwhelmed. Immediate feedback and motivational techniques, such as gamification, are recognized as effective tools to increase engagement and understanding among new users [4].

Beginners have little to no prior knowledge of linear algebra, transformations, or computer graphics and may also lack experience with similar tools or applications. They are motivated by the desire to learn and understand new concepts, prefer structured, step-by-step guidance, and benefit from visual aids and real-time feedback to reinforce their learning. Constructive approaches, where users actively build knowledge through guided exploration and feedback, are especially effective in complex domains such as computer graphics [3]. Beginners may feel overwhelmed by complex interfaces or technical mess, preferring tools that are intuitive, user-friendly, and provide clear instructions.

### 4.2 Advanced Users

Users, such as professional game programmers, need a quick and efficient introduction to how the application works. They do not want to be slowed down by step-by-step explanations, but they need access to detailed information about advanced components and how they function. These users are confident in their abilities and primarily use the tool to test and implement their ideas.

Advanced users have a strong understanding of linear algebra, transformations, and computer graphics and are experienced with similar tools and applications. They are motivated by the need to quickly test and implement their ideas, preferring efficient, streamlined workflows and access to detailed information about advanced components. Advanced users are comfortable with complex interfaces and technical details, valuing tools that are powerful, flexible, and allow for customization.

### 4.3 Teachers

Educators need a well-organized tool with quick access to prepared scenes for lectures. They need to clearly and visibly demonstrate how things work and how changes affect the outcome. Teachers also benefit from features that allow them to create tasks for students, track progress, and provide feedback through quizzes and assessments.

Teachers should have a deep understanding of linear algebra, transformations, and computer graphics and are experienced educators familiar with teaching tools and methodologies. However, some may initially feel hesitant about learning and using new technology, especially if they perceive it as a replacement for their role rather than a supportive tool.

Teachers are motivated by the need to effectively convey concepts to students and enhance their teaching methods, preferring tools that are well organized, easy to use, and allow quick access to prepared scenes and teaching materials. The goal is to save time and effort while improving student engagement and understanding. Teachers value tools that improve their teaching and engage students, but may need reassurance that the tool is designed to support, not replace, their role. They prefer intuitive interfaces, require minimal setup or technical expertise, and provide clear guidance on how to integrate the tool into their teaching practices.

## 4.4 Students

Although students may be similar to beginners, they often have a basic understanding of the theory and use the tool to deepen their knowledge. They benefit from tutorials that broaden their understanding of topics and links to additional resources for further learning. Practices and exercises allow students to apply theories in real time and see how changes affect the outcome.

Students have a basic understanding of linear algebra and computer graphics, but are still developing their skills. They may have some experience with similar tools or applications. Students are motivated by the desire to deepen their knowledge and apply theoretical concepts in practice, benefiting from self-paced learning tools, progress tracking, and visual aids to reinforce their understanding. Students are generally comfortable with technology, but may need guidance when using complex tools, preferring interfaces that are intuitive, engaging, and provide clear feedback.

### 4.5 Focus Areas

Although this thesis considers the needs of all four archetypes, the main focus lies on supporting beginners. Their challenges with onboarding, conceptual understanding, and navigation of the tool highlight the most pressing barriers to effective use. Beginners require structured guidance and feedback to build confidence. For this reason, improvements to the tutorial system and the onboarding interface are focused on making the early stages of interaction clearer, more motivating, and easier to follow.

In parallel, students and teachers receive secondary attention. Students benefit from enhancements that support self-paced exploration and reinforce theoretical understanding, particularly through structured tutorials and exercises. Teachers are considered in the preparation of materials and the creation of teaching scenarios.

Advanced users are acknowledged in the broader usability improvements, especially within the manual. However, the focus of the redesign efforts remains on groups that rely on guidance and structure to fully benefit from the educational potential of the tool.

# Chapter 5

# Manual: Development

The manual serves as a critical knowledge base for I3T users, offering structured guidance and reference material for components not fully covered in tutorials. However, as detailed in Section 3.2.2, the original version of the manual lacked completeness, visual clarity, and structural coherence, making it unsuitable for onboarding or daily use.

Due to these shortcomings, developing a functional and testable version of the manual became a prerequisite for following evaluation phases. Without a readable and informative manual, it would not have been possible to assess the tool's learnability or usability with real users. The redesign process was therefore grounded in usability principles from ISO 9241-11 [8] and documentation standards from ISO 9241-13 [18], along with minimalist instruction heuristics established by van der Meij and Carroll [20].

# 5.1 Changes to the Manual

Restructuring focused on defining a clear information architecture, establishing modular sections aligned with user workflows, and incorporating progressive disclosure to minimize cognitive load. Special attention was paid to supporting multiple user reading strategies, as recommended by van der Meij and Carroll's Principle 4 [20]. The new manual also addresses visual gaps identified during the critique by integrating annotated screenshots, illustrative examples, and animated visual aids where appropriate. These additions are especially important for abstract topics such as transformation composition and coordinate systems, where visual reinforcement improves comprehension.

To provide an overview of key features while allowing users to explore deeper information at their own pace, collapsible sections were introduced for more complex topics. For example, the "Camera and Screen" section presents only the essential controls and descriptions, while expandable subsections offer deeper explanations of the projection matrix and view matrix. This structure also includes links to additional learning resources for users who want to study the mathematical foundations in more detail. As shown in Figure 5.1, this approach addresses earlier problems with overloaded or missing content by presenting the core information upfront while keeping more advanced content easily accessible.

### **▼** Projection Matrix

### **Orthogonal Projection**

- Creates a flat view (e.g., blueprints), where object size remains constant regardless of distance.
- · Use disable synergies to adjust bounds independently.

### **Perspective Projection**

- · Mimics human vision, where objects appear smaller as they move farther away.
- · Commonly used for realistic 3D scenes requiring depth perception.

### ▶ View Matrix

### **▼** Theory

- LookAt
- Projection and viewport
- Projection principle
- Principle of perspective projection
- Viewport
- Orthographic projection (contd.)
- Perspective projection (contd.)
- · Viewport transformation (contd.)

**Figure 5.1:** Collapsible structure used in the Camera and Screen section.

Visual documentation was also a key addition. For example, Figure 5.2 illustrates a node setup showing translation, rotation, and scaling within a sequence node used to apply transformations to models.

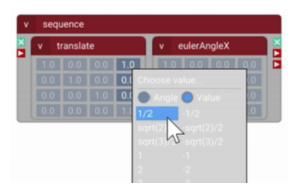
### **Transformations**

Transformations are always inserted into sequences. The order can be arbitrary. A typical order is **Translation, Rotation, Scaling (TRS)**.



**Figure 5.2:** Screenshot from the manual showing matrix operations in a node graph.

To further enhance clarity, GIF animations were used to demonstrate multiple ways of modifying matrix values and to make interaction options more discoverable (see Figure 5.3).



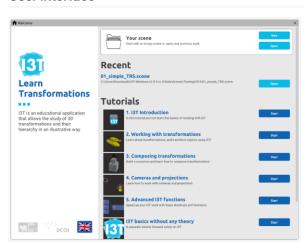
**Figure 5.3:** Screenshot of a GIF from the manual demonstrating matrix input methods.

To support users studying or reviewing theoretical background, the manual also integrates internal links to relevant external resources on mathematical concepts, especially those related to transformations and projections.

The new structure mirrors the internal organization of the application and follows a three-part framework.

The first part introduces the user interface, including window layout, controls, menus, toolbars, and keyboard shortcuts (see Figure 5.4). This provides users with an overview of the working environment and the means of navigation.

### User interface



The program begins with the **Start Window**, which allows you to choose between tutorials, opening an existing scene, or creating a new one. Once selected, the program enters the Workspace mode, consisting of two main windows.

Figure 5.4: Section of the manual showing the Start Window layout.

cycle
Delete
Selection
Zoom

The second part provides technical documentation for the workspace, describing the node system, node types, their connections, and usage patterns (see Figure 5.5). This supports both sequential learning and quick reference for modeling and transformation workflows.

# Workspace The Workspace window is where scenes are assembled. You can add, connect, and manipulate nodes to create the desired transformations and models. Adding Nodes Add... transformation operator sequence camera model pulse screen

• To add node, right-click anywhere in the Workspace to open the context menu

**Figure 5.5:** Manual content illustrating node setup and transformation logic in the workspace.

The third part focuses on the scene view, detailing the visual output of workspace nodes and explaining how to use manipulators and configure rendering settings (see Figure 5.6). This section helps users understand how changes in the workspace are visually reflected and controlled in the 3D view.

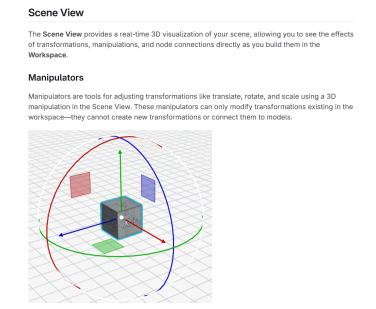


Figure 5.6: Scene view documentation showing manipulators.

This restructured manual now serves both as an onboarding resource and a detailed reference, addressing the usability and documentation gaps identified in the earlier analysis. It provided the necessary foundation for usability testing, as described in Chapter 6.4, where students evaluated its clarity, completeness, and accessibility. The final version submitted for testing and feedback is available in Appendix C.2.

# Chapter 6

# **Teaching Scenarios**

This chapter focuses primarily on two archetypes, teachers and students (see Chapter 4), and explores how the application can be used effectively in classroom settings. The goal is to determine the most suitable teaching approaches for supporting the understanding of transformations in these contexts.

In the context of the PGR course, the application is used in lectures as a visual aid to demonstrate the transformation processes discussed in class. This visual support helps connect abstract mathematical concepts with concrete graphical examples.

The emphasis is on structured educational use, but the findings also offer valuable insight into broader usability issues and learning challenges that may affect other user types, such as beginners or advanced users working independently. By examining how the tool performs in a real teaching environment, we uncover patterns that inform not only pedagogical improvements but also general application design.

Each student possesses a unique learning style and pace, and since university students often approach their studies individually, a single "best" teaching method is unrealistic. Therefore, this chapter seeks to identify strategies that accommodate the majority while enabling flexibility for different needs. Such flexible learning environments are critical for supporting student autonomy and mastery, as emphasized in game-based scaffolding research [17].

# **6.1** Evaluation of the Teaching Path

The application is actively used during the Computer Graphics (PGR) course as a key tool to understand and apply 3D transformations. It is also recom-

mended as a supplementary resource for students enrolled in Linear Algebra courses. These students are from technical faculties and typically have prior exposure to mathematical concepts relevant to transformations or are learning them in parallel as part of their curriculum.

Upon launching the application, users can begin with foundational tutorials that introduce essential transformation concepts. The learning path is designed to progress in complexity, from basic operations, such as translation, rotation, and scaling, to more advanced topics, including transformation sequences and projections. This progressive structure aligns with previous findings that emphasize how incorporating fun and exploration into computer game-based learning can improve motivation and educational outcomes [25]. As covered in Section 6.3, these elements are tested through quizzes and tasks integrated with classroom activities.

Although the current path offers a structured and logical learning flow, it presents several limitations. Lectures would benefit from more condensed and focused presentations that allow for quick comprehension in class, followed by more detailed materials for independent study. Students are typically introduced to the application for the first time during lectures, where it helps visualize mathematical concepts in practice; however, frequent switching between the already dense slides and the application may cause confusion. In practice sessions, the application is not yet self-sufficient as a standalone teaching tool, its successful integration still depends heavily on the teacher's guidance.

# **6.2** Preparation of Two Week Teaching Scenarios

As noted in Section 6.1, the application's structured learning path was implemented through multiple teaching scenarios that were created and refined. I also revised the materials for the Computer Graphics class (PGR). These revisions included short quizzes to assess theoretical understanding, classroom practice assignments using I3T, and take-home exercises for independent learning.

Each part was aligned with specific curriculum components and directly linked to application functionality. Coller and Scott [26] showed that a similar approach is effective, who demonstrated that integrating interactive games into engineering curricula can significantly improve student engagement and learning outcomes.

The goal was to ensure students completed technical tasks in I3T and understood the underlying mathematical concepts. The primary focus was to revise, teach new and more advanced topics, prepare students for testing at the end of the two weeks focused on transformations, and gather feedback.

#### 6.2.1 First Week and Basics

Initially, students should be given the freedom to explore the application independently. Recognizing potential hesitation to download new software, I integrated the application into the required weekly quiz. The plan was first to allow exploration, then review tutorials, familiarize students with the application, and have them complete a simple task easily achievable with the provided materials and tutorials connected to the week's themes and learning objectives. As this was the initial introduction to transformations, the questions were designed to be a reminder/repetition of introductory linear algebra concepts.

I first prepared the learning objectives, outlining key linear algebra concepts for review: vectors, matrix operations, fundamental transformations (translation, rotation, scaling), understanding linear independence, transformation composition, matrix multiplication order, memorizing dot/cross product formulas, basic 4x4 matrices, and homogeneous coordinates. I also prepared a tutorial on downloading the application for different operating systems.

After defining the learning objectives, I focused on the first quiz. The first part was made to gather user feedback on the application, tutorials, manual (see the version used in testing in Appendix C.2), and overall impression, including suggestions for improvement and classroom integration. Following the feedback section, the quiz assesses knowledge by directly referencing the prepared materials and presentation slides, concluding with a practical task using the application to apply fundamental transformations to a model.

## 6.2.2 Second Week and Advanced Topics

For the second week, the focus needed to be on the continuation of the topic, including a review of linear and affine transformations, radians and degrees, rigid transformations, coordinate systems, and an overview of camera, perspective, and orthogonal projection. A tutorial in I3T focusing on camera and projections was assigned, allowing students to experiment firsthand.

The second quiz was made to focus solely on theory, reviewing the previous lecture and assessing understanding of the week's learning objectives, again ending with a practical application task now to demonstrate the differences between projections.

I instructed the teacher to use the application at the start of the lecture to showcase incorrect answers visually to help students understand their mistakes by seeing the consequences rather than being told a number was wrong.

## 6.2.3 Final Practice Session and Testing Quiz

The most crucial part was preparing a teaching plan for the final practice session. The essential element was an initial review of the basics, anticipating that many students may have missed the lecture, to review and prepare them for more complex topics. Following the revision of prepared materials, a series of topics from previous years need to be presented, where the teacher first explains the mathematical concepts and demonstrates them on a whiteboard. Then, visual explanations using pre-existing scenes are presented. This approach allows students to take notes, ask questions, and visually explore the topic interactively. Topics needed to include advanced topics, such as transition matrix construction, transformation from A to B, gimbal lock, rigidity, and projection.

Following that, I created the final quiz and prepared it to be assigned after the practice session, as this is the optimal time to gather honest opinions on the application. After the practice, they had the best opportunity to explore it, which many likely had not done extensively until then. The questions are directly derived from the topics covered in class, emphasizing understanding and comprehension. The final section is a questionnaire and feedback form designed to provide the best overview of user satisfaction.

## 6.2.4 Competition

To complete the course preparation, I introduced a bonus task: a competition for the best scene created in I3T. This activity offered students an opportunity to apply their knowledge creatively while earning additional credit. The assignment included two thematic options: designing an optical illusion or creating a free scene that demonstrated their understanding of transformations covered in the course.

## 6.2.5 Evaluation Design

This variety of approaches, combining lectures, I3T visuals, and individual tasks, is key to reaching the widest audience by accommodating different learning styles.

The evaluation design was inspired by the Technology Acceptance Model (TAM), which is widely used to evaluate user acceptance and interaction with new technologies. Although the testing was not formally structured as a full TAM study, its core constructs were adopted to guide the design of feedback instruments and to assess perceived educational utility and usability, both essential factors for application adoption.

# 6.3 User Testing

This section presents the methodology for evaluating I3T's implementation in educational practice. The study employed a mixed-methods approach across multiple classroom contexts, combining practical application with theoretical instruction. Data collection focused on both user interaction patterns and learning outcomes, providing a comprehensive assessment of the application's real-world effectiveness. The testing took a place in two school weeks as described in Chapter 6.2

## 6.3.1 Participants

The testing was carried out in the Computer Graphics (PGR) course, which is mandatory for most students and is typically taken during the second or third year of undergraduate studies. The participants were students from two faculties: the Faculty of Electrical Engineering (FEL), which represented approximately 58% of the group, and the Faculty of Information Technology (FIT), which made up the remaining 42%. All participants had prior exposure to linear algebra, one semester for FEL students and two semesters for FIT students, and varying levels of programming experience. Around 12% of the students were retaking the course for the second time.

Both instructors involved in the testing are from FEL and part of the Department of Computer Graphics and Interaction. They have a deep understanding of the subject matter and participated in the preparation of all teaching materials. One of them, the course lecturer, had already started using the I3T application in previous years as a visual aid during lectures. Both teachers were also involved in the first experimental application of I3T in practical sessions in the previous academic year.

## 6.3.2 First Week of Testing

Following the teaching scenarios prepared in Section 6.2, the first round of testing was conducted with 86 students as part of the PGR course. As described in Section 6.3.1, the participants came from FEL and FIT and had prior exposure to linear algebra and basic programming.

Students were encouraged to work independently with the application as preparation for the lecture on transformations, exploring the application, and completing set tutorials.

Then they completed a structured feedback form (see Appendix D.4.1) that covered the clarity, structure, length, interactivity, and experience of the

tutorial using the manual. In addition, they completed a quiz (as seen in Appendix D.1.1) that tested their understanding of key concepts related to vector and matrix transformations and their ability to perform transformation sequences within I3T. Students also submitted a screenshot of a completed task to confirm their practical application.

After this initial introduction, students saw scenes from the application that were used as visuals in a lecture to reinforce the topics. Students who were already familiar with the application now had better chances of understanding it.

The second quiz, completed by 83 students, focused solely on theory, assessing understanding of topics discussed the previous week, and providing insight into the upcoming week.

## 6.3.3 Second Week of Testing and In-Class Use

The final quiz was performed in the second week. As mentioned in preparations, students first attended a class session where the instructor explained relevant theory and demonstrated problems in I3T. The students could follow the teacher, explore and try independently.

This round of testing involved 79 students. This large-scale testing followed a format of both quantitative results and satisfaction feedback.

The quiz covered the topics of the practice. The feedback covered areas like clarity and structure, logic and usability, educational impact compared to traditional theory, points of confusion, missing features, helpful aspects, and suggestions for improved classroom use.

## 6.3.4 Summary and Model Alignment

The real course setting, with its authentic curriculum and mandatory participation, yielded particularly useful information on how I3T performs under actual teaching conditions. Feedback captured not just the application's usability but also its effectiveness compared to traditional teaching methods and its ability to overcome common learning barriers in transformation theory.

As introduced in Section 6.2.5, the testing was not a formally structured TAM study but was informed by its principles. TAM is widely used to evaluate user acceptance and interaction with new technologies and served as a helpful framework for interpreting feedback results.

Student feedback focused on two main areas: perceived usefulness, which assessed whether students found the I3T application effective for learning,

and perceived ease of use, which evaluated the clarity of tutorials and the usability of the interface. This feedback provided valuable insights into students' acceptance of the I3T in its original form, reflecting their attitudes and willingness to engage with the tool as both a visual aid during lectures and a hands-on practice environment for exploring 3D transformations.

## 6.4 Results and Observations

This chapter presents a structured evaluation of the I3T application's impact on learning outcomes, usability, and student engagement. Building upon the testing design detailed throughout Chapter 6 and the participant characteristics outlined in Section 6.3.1, the evaluation combined theoretical instruction, practical scenarios, and structured quizzes to collect comprehensive feedback from more than 80 students.

Building the usability framework defined in ISO 9241-11:2018 [27] and TAM framework established in Section 6.3.4, this evaluation focuses on effectiveness, efficiency, user satisfaction and frame student feedback around perceived usefulness and perceived ease of use. The complete assessment instruments are archived in the Appendix D.

### 6.4.1 Quiz Observations

The questions aimed to evaluate how well the students could apply theoretical knowledge and reason about transformations in practice. As noted in Section 6.2, all quizzes were prepared based on previous course content, reviewed by the supervising lecturer, and used not only for assessment but also as a teaching aid. Incorrect answers were revisited at the beginning of lectures using I3T to illustrate misunderstandings in context, supporting in-class discussion and reflection.

Students demonstrated strong foundational understanding of vector operations and matrix algebra. Most were able to provide both algebraic formulas and geometric interpretations of the dot product, while only a few answers showed minor confusion between scalar and vector products. Matrix multiplication was also well understood, with common errors largely limited to syntax or minor arithmetic slips, not conceptual gaps.

More complex applied questions, including identifying transformations from matrices or explaining the graphics pipeline, were handled confidently. Students correctly recognized sequences of transformations and gave valid reasoning for projection differences. A few responses misordered transformations, which supports the case for adding visual cues or step-by-step breakdowns in

tutorials.

In general, the answers demonstrated a successful understanding of mathematical theory and its practical application. This strongly suggests that the instructional approach, combining lectures, guided I3T interaction, and testing, effectively supports educational goals. Aligned with ISO 9241-11:2018 [27], this reflects high effectiveness in user performance within the defined context of use, while the preparation of structured scenarios and alignment with user needs are consistent with the design principles of ISO 9241-210:2020 [8]. Furthermore, this iterative refinement process reflects the established best practice of early and repeated usability testing to improve system acceptance and satisfaction [9].

Furthermore, these findings are consistent with previous research by Coller and Scott [26] and Charsky and Ressler [25], which highlight the importance of interactive, game-based learning approaches for improving conceptual understanding and engagement in technical education.

## 6.4.2 Quantitative Knowledge Testing

The final comprehensive quiz tested understanding of transformation principles. Each question evaluated specific knowledge areas, including transformation types, coordinate conversions, and projection logic. These topics were carefully selected according to the teaching plan (Section 6.2).

Question	FEL A	FEL B	FIT A	Total
X1 – Type of transformation	100%	69%	88%	88%
$X2$ – Transform $A \rightarrow B$	97%	75%	88%	88%
X3 – New axes from original	34%	44%	33%	36%
X3 (Partial answer)	62%	38%	49%	51%
X4 – Gimbal Lock	100%	88%	94%	95%
X5 – Perspective vs Orthographic	97%	100%	94%	96%

**Table 6.1:** Correct and Partial Answers by Group and Question (Comprehensive Test)

As seen in Table 6.1 (complete data in Appendix D.3.1), the results indicate a strong understanding of key transformation concepts among students. Questions X1, X4, and X5 focused on identifying the nature of transformation matrices, the Gimbal Lock, and distinguishing projection types. Students demonstrated high accuracy rates, indicating strong comprehension and effective instructional alignment.

The coordinated use of I3T in lectures and exercises, especially through the structured teaching plan for the final practice session, appears to have contributed to these results. Inclusion of visual demonstrations, hands-on exercises, and reinforcement through tutorials helped students apply abstract theory more concretely.

On the other hand, Question X3, which tested the derivation of axes in a new coordinate system, presented the greatest challenge. Although fewer students answered it fully correctly, more than half provided partially correct solutions. This suggests that the concept was partially understood, but would benefit from additional breakdown or a dedicated tutorial within I3T.

Although there were some performance differences between the groups, the general trend indicates a consistent improvement among the participants. These variations likely reflect different classroom dynamics, timing, or teacher approaches. The consistently high performance in conceptual questions strongly suggests that the application and associated materials were broadly accessible and impactful.

## 6.4.3 Feedback

User feedback collected during both testing rounds (see Appendix D.4.1 and Appendix D.4.2) focused on evaluating the clarity of the tutorial, the usability of the application and the perceived educational value. The responses reflect the subjective impressions of the students of working with I3T and provide insight into perceived ease of use, perceived usefulness, user satisfaction, and effectiveness.

## Key Strengths

Students identified several key strengths in I3T, with tutorials being the most often praised feature. Many appreciated the ability to revisit specific topics independently, particularly LookAt and projection matrices. The visual feedback system received equal emphasis, and the students reported that the visualization of the real-time matrix helped clarify abstract operations and enabled deeper understanding. Additional valued features included transformation tools for instant outcome visualization, camera controls, and integration of visual scenes with theoretical concepts.

## Quantitative Findings

Figure 6.1 summarizes the ratings for tutorial comprehensibility. A significant majority of students (83%) rated the tutorials as either very easy or easy to understand, strongly suggesting that the structure and content effectively met user expectations for clarity and onboarding. The small percentage of students who found the tutorials challenging likely reflects individual differences in prior experience or learning styles.

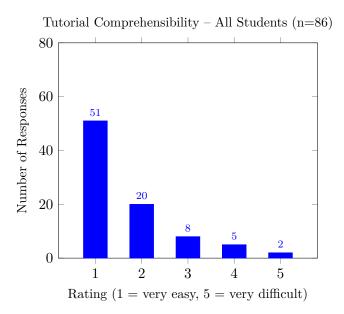


Figure 6.1: Ratings of how easy the tutorials were to understand (All students).

Figure 6.2 presents the percentage of "Yes" responses to selected usability and instructional design questions regarding manual. In particular, 85% of the students reported that the tutorials were clearly structured (Y2) and 94% considered the flow logical (Y3). While 49% supported gamification (Y6) or integrated quizzes (Y7), a slight majority (51%) expressed neutrality or preferred traditional formats. This aids the conclusion that optional gamification could enhance engagement for some learners without disrupting those who prefer traditional methods, a finding consistent with González-Campos et al. [7] and similar design considerations outlined in [28].

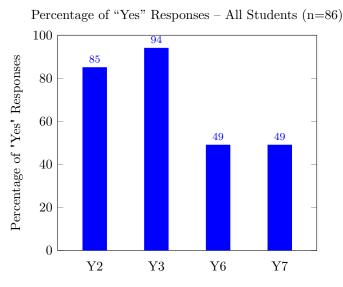


Figure 6.2: Percentage of "Yes" answers to questions about tutorials.

Manual usage patterns exhibited greater variability (as seen in Figure 6.3. Although only 38% of students used the manual for tutorials (Question Y8), those who did generally found it beneficial. In fact, 95% of these users rated the manual as easy to navigate (Question Y10), and 75% desired integrated theoretical links (Question Y9). These findings underscore the manual's potential value and suggest that improved discoverability could significantly increase its adoption. Documentation proves most effective when it provides targeted help at the point of need, as specified in ISO 9241-13:1999 [18].

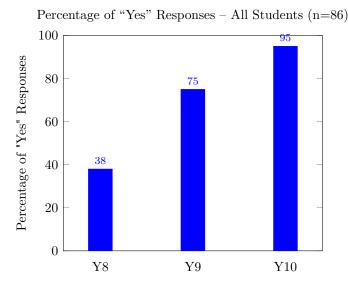


Figure 6.3: Percentage of "Yes" answers to questions about manual.

Table 6.2 presents cumulative feedback ratings across three important questions. Most of the students found the interface easy to understand (Z1), had a positive working experience with I3T (Z2), and considered it helpful to understand transformations (Z3). These findings reflect strong *perceived usefulness* and *ease of use* and confirm that I3T meets essential usability expectations.

Question	1	2	3	4	5
Z1 – Ease of understanding controls	43	30	4	1	0
Z2 – Working experience with I3T	25	45	6	2	0
Z3 – Helpfulness in understanding theory	35	33	9	0	1

Scale Legend:  $1 = \text{Very easy} / \text{Very helpful}, \quad 5 = \text{Very difficult} / \text{Not at all helpful}$ 

**Table 6.2:** Cumulative Feedback Ratings from All Students (n=78)

## Interface Challenges

Student feedback highlighted several recurring interface limitations. The most frequently mentioned issue was the lack of effective touchpad control, particularly the absence of emulation of the middle mouse button (MMB) emulation, which complicated camera movement and workspace navigation on laptops. The students also reported the small size of connection slots for linking nodes, which became difficult to use when zoomed out.

Additional problems included missing scrollbars in the workspace menu, difficulty accessing menus near the lower screen edge, unintuitive interaction for editing matrix values, and lack of expected keyboard shortcuts (such as Shift+A for adding nodes). Some users noted occasional malfunction of undo/redo functions and expressed the need for improved visibility and consistency of workspace controls. Several suggestions referenced Blender's interface conventions as a possible model for improvement.

These findings indicate specific opportunities to optimize task execution, simplify interactions, and introduce alternative input modes in accordance with the ISO 9241-110:2020 guidelines for interaction efficiency and error tolerance [11].

## Educational Use and Student Sentiment

A total of 38 students suggested potential applications for I3T beyond the original Computer Graphics course. The most common proposal was to integrate the tool into linear algebra instruction (courses LA1 and LA2), where students considered it suitable for illustrating bases, transformation matrices, and changes of coordinate systems.

Multiple responses requested the addition of more advanced exercises, including tasks in which objects would be moved and rotated between defined points. Further suggestions included expanding the tutorial library, introducing guided derivation of transformation matrices, and adding scoring mechanisms to support classroom activity tracking. Individual students also proposed potential uses in game development, shader visualization, and as a supplementary visualization aid in lectures.

These recommendations reflect the interest of students in expanding I3T as an educational tool in related courses. They are consistent with previous research showing the positive effects of interactive games-based environments to improve engagement and learning outcomes in STEM education [25, 26].

The open comments offered positive feedback on I3T clarity, learning speed, and teaching innovation. Several mentioned that concepts they previously

struggled with 'finally clicked'. Others appreciated the application's evolution and its integration into lectures. These remarks show strong user satisfaction and support the continued refinement and expansion of the application.

## 6.4.4 Comparative Analysis of Student Groups

The evaluation included five classes in total: two from FIT and three from FEL. Four of these were taught by Teacher A, two FIT groups and two FEL groups, while the fifth, a FEL group, was taught by Teacher B. This structure allowed for two valuable comparisons: the influence of faculty background under identical instruction and the impact of teaching approach when working with similar student profiles.

The overall student distribution was relatively stable across all three testing phases, with slightly more students from FEL than FIT in each case. This balance, illustrated in Figure 6.4, supports the reliability of faculty-based comparisons throughout the evaluation.

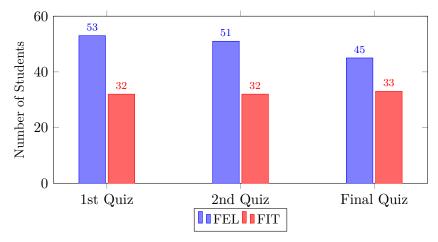


Figure 6.4: Distribution of FEL and FIT students across all quizzes.

Teacher A taught all four of their classes using the same plan and method, and I was present for each session to confirm consistency. Therefore, any differences in results between FIT and FEL students can reasonably be attributed to differences in academic background rather than instructional delivery. The results in the FIT and FEL groups were generally similar, with only minor variations in manual use or depth of feedback. These findings indicate that the I3T materials and activities were well suited to students from both faculties, regardless of differences in prior knowledge.

A more noticeable contrast was shown when comparing the two FEL groups taught by different instructors. Although both teachers received the same materials and scenario outlines, their delivery styles diverged. Teacher A began each session with a detailed and structured review of the core con-

cepts. This was followed by my prepared topics (as seen in Appendix C.4), which included a theoretical explanation on the whiteboard, followed by an interactive demonstration using pre-prepared I3T scenes and leaving time for students to try these on their own.

In contrast, Teacher B conducted only a brief theoretical review and focused more heavily on using I3T as the primary instructional aid. Their lessons emphasized real-time exploration and explanation within the application itself, providing more immediate visual feedback but less preparatory theory on the board. Although both approaches followed the same core plan, this difference in delivery style may help explain the lower quiz scores observed in the Teacher B group. As shown in Table 6.1, Teacher A's group (FEL A) achieved notably higher scores than Teacher B's group (FEL B), particularly on fundamental concept questions such as identifying the type of transformation (100% vs. 69%) and solving transformation from A to B (97% vs. 75%). However, the Teacher B group slightly outperformed on the more visually oriented topic of perspective versus orthographic projection (100% vs. 97%), suggesting that this teaching style may have been more effective for certain spatial or visual tasks.

These comparisons underline the importance of the teacher's role and the theoretical explanation in the integration of digital tools such as I3T into classes. The application performed well in both cases, but the highest outcomes were observed where guided explanation and visualization were used together. This highlights the role of scaffolding and instructional timing in maximizing the educational impact of interactive learning environments.

# Chapter 7

# Improvements Made and Ideas For Future Development

Based on the identified system gaps (Chapter 3, Section 3.2), four user archetype requirements (Chapter 4), and teaching path evaluation (Chapter 6, Section 6.1), this chapter proposes targeted enhancements to I3T's learning environment. Drawing from the comprehensive tutorial analysis (Chapter 3.2.1) and the user testing results (Section 6.4), it presents prioritized solutions that address the most critical usability and educational gaps. Each section consists of improvements already implemented, followed by proposals for further development. The implemented changes focus on immediate user needs, while the proposed ideas establish a framework for long-term growth.

## 7.1 Manual

Following the initial restructuring described in Chapter C.2, the updated manual was positively evaluated by the students who used it, with 95% reporting that it was easy to navigate and with minor suggestions. However, it was also evident that the overall discoverability remained low, as only 38% of the students actively used the manual during tutorials (see Section 6.4.3). This highlights a key challenge; although the manual is useful and generally well-structured, many users are unaware of its existence or fail to access it when they need it.

## 7.1.1 Implementation

In response, the manual was updated to better align with the user needs identified in the testing and adjusted after consultation with the thesis supervisor. Based on feedback, more direct links to theoretical materials were added, particularly in sections describing matrices, transformation composition, and projections. This change specifically benefits beginners, who frequently requested integrated theoretical support to help them connect practical tasks with underlying concepts (see Chapter 4). At the same time, experienced students and advanced users gain a faster reference to explore more complex operations. The improvements also help teachers by making it easier to guide students through application tasks and recommend targeted reading.

In addition, the structure was adjusted in following places to improve clarity and flow. For example, five new visuals were introduced to enhance comprehension, particularly in areas such as camera controls, and "Operators" were moved higher in front of "Cycle" as that is a very advanced topic still in development. These changes respond to user feedback on the logical ordering of information, improving both the onboarding experience for beginners and navigation for advanced users.

To keep the manual in alignment with the evolving application, a collaborative workflow was proposed for future updates. Developers adding new features are now encouraged to update the documentation alongside their code contributions. This approach helps maintain accurate documentation and supports long-term consistency between the manual and the software, important for *advanced users* and *students* reviewing the tool independently.

## 7.1.2 Proposals

A major planned improvement is the implementation of an offline manual viewer directly within the application. This feature will utilize the already integrated imgui\_markdown library to display formatted help content in a dedicated window. By embedding the manual inside the user interface, users would no longer need to switch contexts or rely on an internet connection, significantly improving discoverability and access to support materials for all user groups, especially beginners with on-demand help during tasks. Such contextual help systems are aligned with the recommendations in ISO 9241-13:1999 [18], which emphasize the value of accessible just-in-time guidance within interactive systems.

## 7.2 Tutorials

Tutorials serve as the primary onboarding mechanism for new users of any archetype and an essential guide for understanding how to operate the I3T application. Although existing tutorials covered the core components of

the interface, their static nature, lack of progress tracking, and insufficient coverage of advanced topics limited their effectiveness. As noted in the detailed evaluation of the tutorial in Appendix 3.2.1, key issues included inconsistent instructional flow, minimal theoretical integration, and gaps in clarity regarding component functionality. These limitations were echoed in user feedback, where *students* and *beginners* in particular requested clearer structure, better interactivity, and more comprehensive content coverage (see Section 6.4.3).

## 7.2.1 Implementation

In response, a new introductory tutorial was designed specifically to address the needs of complete beginners. This tutorial introduces users to the application step by step, progressively unveiling interface elements and key features. It places a stronger emphasis on guidance and clarity, aiming to reduce initial cognitive load as described in the user archetypes in Chapter 4 and in alignment with van der Meij and Carroll's minimalist instruction principles [20], which recommend task-focused support to enable learning by doing. The new tutorial (as seen in Appendix C.3) also integrates references to the manual at relevant moments, improving discoverability and guiding users, especially beginners and students, toward more in-depth explanations when needed.

Another significant refinement was the improvement of the internal task verification script and its usage in the new tutorial, initially created as part of the scripting exercise, which checks the workspace for the presence of required nodes and verifies whether users have completed specific actions correctly before moving on to the next step. The earlier version experienced problems when users modified or deleted key nodes, preventing further progression. These issues were resolved for the tutorial use case by redesigning the check mechanism, improving reliability and learner autonomy.

## 7.2.2 Proposals

A major planned enhancement is the implementation of tutorial progress saving, which would allow users to pause and resume tutorials across sessions. This is particularly valuable for *students* working across multiple sessions and for *teachers* preparing structured classroom workflows. The main obstacle to date has been the lack of an internal save-state system that could safely track partial progress. As users complete tasks or entire tutorials, new content could be unlocked sequentially, helping guide beginners through a structured learning path while gradually increasing complexity. The integration of the tutorial progression was deferred due to unresolved dependencies. Various implementation options were discussed, such as embedding progress in tutorial

files, generating saved copies, or creating a separate progress tracking system. The third option was considered to be the most viable, as it avoids overwriting the base files or duplicating the content. However, work on this feature was postponed because of overlap with a parallel work by another student who was exploring save-state and layout-switching mechanisms. To avoid conflicting data structures, the progression system remains a proposed extension to be developed after the scene layout saving system is finalized.

Beyond individual progression, additional exercises are also planned to directly support classroom use. These would mirror live demonstrations shown by teachers in lectures on specific topics such as understanding coordinate systems, constructing transformation matrices, practicing transformation composition, and working with camera views and projections. By aligning in-app tasks with the structure of the course, students would be able to follow the teacher interactively and then complete similar tasks on their own. This dual-use approach improves both understanding and retention, especially for students who benefit from visual repetition and hands-on learning.

Finally, expanding the library to include folders containing more topics, such as lecture scenes and frequent mistakes in transformations, remain a key development goal. They should cover topics such as operators, cycle, gimbal lock, rigid body transformations, and hierarchical transformations.

These enhancements collectively aim to improve usability, support different learning needs, and ensure that tutorials remain an effective learning tool throughout the user's interaction with the application.

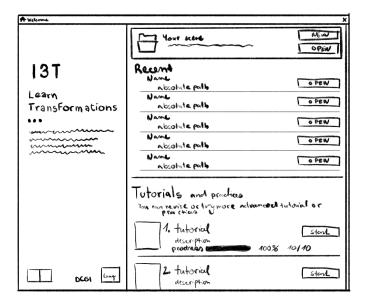
## 7.3 Welcome Window

The welcome window is the first interface users encounter when launching the I3T application, making it a crucial component for orientation and onboarding. As discussed in Section 3.2.3, its original static design offered minimal guidance, lacked access to recent files, and presented no indication of user progress, issues that significantly limited its usefulness for both *beginners* and more experienced users such as *students* and *teachers*.

## 7.3.1 Implementation

To address these shortcomings, a redesigned layout was proposed, supported by design sketches exploring clearer organization and tutorial progression (see Figure 7.1).

The new implemented version (as seen in Figure 7.2) introduces section headers and a dedicated 'Recent' area, allowing users to quickly reopen

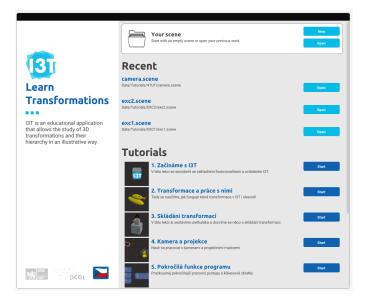


**Figure 7.1:** Design sketches with proposed improvements.

previously used scenes. This benefits *students* returning to exercises, *teachers* revisiting teaching materials, and *advanced users* working on ongoing projects. The layout aligns with ISO 9241-115 recommendations for interface clarity and efficient access to frequent actions [29]. It also reflects common usability patterns in other tools referenced during the analysis, such as Blender and Visual Studio.

## 7.3.2 Proposals

Although this redesign significantly improves usability, two important enhancements, user role-based layouts and tutorial progress tracking, remain conceptual. The goal was to make the welcome window adaptive, showing different content according to the type of user (as defined in Chapter 4). For example, students would see coursework-linked tutorials, teachers would access stored classroom scenes, and advanced users would be offered streamlined access to their recent projects. However, implementation of this feature would require deeper architectural changes, including a profile system, data handling, tutorial and exercise progression as described in Section 7.2.2, and was therefore not achievable within the current development scope. These future directions reflect the need for better onboarding, personalization, and feedback mechanisms directly at the start of the application.



**Figure 7.2:** Implemented welcome window showing the new Recent section and headers.

# 7.4 Teaching Framework

Although the integration of I3T into classroom instruction has demonstrated considerable educational potential, the tests also revealed several challenges related to its integration into teaching workflows.

These proposals aim to make classroom use of I3T more consistent, less overwhelming and better aligned with how students learn and absorb new information.

One major issue was cognitive overload during lectures. Although this was not formally measured, it was observed both through my own experience as a student in a previous year and through informal feedback gathered from students during this year's classroom observations. Many students reported feeling overwhelmed when trying to follow theoretical explanations, take notes, and simultaneously follow demonstrations in I3T. This difficulty was particularly noticeable when the instructor alternated between theoretical slides, application demonstrations, and live examples. For example, in the first lecture on transformations, the teacher frequently switched between slides (such as jumping from slide 17 to 32, then to 52 and back to 43) and the I3T application, which further contributed to student confusion and disrupted the learning flow.

In the practice classes, the structure of the session was revised to establish a clearer and more consistent teaching flow. The revised session plan (documented in Appendix C.4) emphasized starting with a structured recap

of basic concepts and theoretical explanations on the board, followed by visual demonstrations using pre-prepared scenes in I3T, and ending with opportunities for students to replicate the tasks on their own. This structure helped reduce interruptions, improved classroom flow, and made it easier for students to follow.

Looking ahead, three improvements are proposed to support better classroom integration. One key idea is the creation of a dedicated folder or scene library for lecture and practice use. This collection would include scenes that illustrate key concepts and common mistakes (for example, those found in quizzes), making it easier for teachers to explain difficult topics and for students to revisit these examples independently.

Another proposal focuses on streamlining classroom materials. Instead of relying solely on dense presentations during class, shorter and more focused versions of teaching content would be used. These condensed materials would present only the key points needed for classroom understanding, while more detailed explanations would remain available in the supplementary resources. This approach avoids frequent context switching and reduces the cognitive load on students during lessons.

Finally, it is recommended to adjust the course timeline by moving transformation topics to the beginning of the semester. Since most students already have some familiarity with basic transformations from linear algebra, this change would offer a smoother introduction to the subject before progressing into more advanced and less intuitive topics like buffers and rendering pipelines.

# Chapter 8

## **Conclusion**

This thesis aimed to improve the educational effectiveness of the Interactive Tool for Teaching Transformations (I3T), developed by the Department of Computer Graphics and Interaction. Through a combination of system analysis, user modeling, literature grounding, and user testing, the work achieved measurable progress toward improving I3T's usability, adaptability, and learning support for diverse user types, particularly in onboarding, documentation, and classroom use, as evidenced by structured feedback from over 80 students, quiz performance data, and classroom observation.

An in-depth evaluation of the existing system revealed key issues in the tutorials, manual, and welcome interface, particularly in accessibility, structure, and theoretical integration. Based on this, role-based user archetypes were defined to guide improvements tailored to beginners, advanced users, students, and teachers.

The major enhancements included a redesigned manual with clearer structure and theory links, a new tutorial with improved onboarding and verification, and restructured welcome window. These changes followed user-centered design principles, incorporated established instructional design heuristics, and were aligned with ISO usability standards and the Technology Acceptance Model (TAM).

User testing with more than 80 students confirmed that the updated version of I3T, supported by revised materials and a restructured teaching approach, improved comprehension, engagement, and perceived usability. The integration of I3T into guided teaching scenarios helped students connect abstract theory to visual practice more effectively.

All the objectives of the thesis were successfully achieved. The tool was thoroughly analyzed, improved through iterative design, tested with users, and refined based on their feedback. As a result, it is now better suited both for classroom and individual use.

8. Conclusion

The planned future development includes features such as tutorial progress tracking, expanded tutorial libraries, integrated in-application help, and optional gamification to boost engagement. Ongoing collaboration with educators will be essential to align I3T with real classroom needs and to support its continued evolution as an effective tool for teaching transformations.

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 $\operatorname{PVM}$ 

# Appendix A List of Abbreviations

Projection-View-Model matrix

I3T	Interactive Tool for Teaching Transformations
UX	User Experience
UI	User Interface
UCD	User-Centered Design
PGR	Počítačová Grafika (Computer Graphics course)
FEL	Faculty of Electrical Engineering (Fakulta Elektrotechnická)
FIT	Faculty of Information Technology (Fakulta Informačních Technologií)
TAM	Technology Acceptance Model
ISO	International Organization for Standardization
$\operatorname{GIF}$	Graphics Interchange Format
TRS	Translation-Rotation-Scaling

# Appendix B Used Software

In accordance with the Methodological guideline No.  $5/2023^{1}$ , the following software was used in the development of this thesis:

- ChatGPT (OpenAI)<sup>2</sup> for text style feedback and rephrasing suggestions
- Grammarly³ for grammar and spelling checking
- Anara<sup>4</sup> for research papers, citations, and rephrasing suggestions

https://www.cvut.cz/sites/default/files/content/ d1dc93cd-5894-4521-b799-c7e715d3c59e/en/20231003-methodological-guideline-no-52023.

<sup>&</sup>lt;sup>2</sup>https://chat.openai.com/

<sup>3</sup>https://www.grammarly.com/

<sup>4</sup>https://anara.com/

# Appendix C

# **Attached files**

## C.1 Old Manual

The original manual for the application is provided in the file OldI3TManual.pdf.

# C.2 New Manual

The new user manual for the application is provided in the file New13tManual.pdf.

# **C.3** New Introductory Tutorial

The new tutorial is provided in the file NewI3TTutorial.tut and visually in NewI3TTutorial.pdf.

# C.4 Class Scenario

The new class scenario for practice classes is provided in the file NewI3tClassScenario.pdf.

# Appendix D

# **Quizzes and Questionnaires**

This section presents the quiz content and feedback questionnaires used for evaluating the original state of I3T.

# D.1 First Week Quiz

## **D.1.1** Questions

- 1. Write the formula for the dot product of two vectors.
- 2. What does the dot product tell us about the angle between two vectors?
- 3. Multiply the following matrices and write the result row by row:

$$\begin{pmatrix} 1 & 2 \\ 3 & 4 \end{pmatrix} \times \begin{pmatrix} 5 & 6 \\ 7 & 8 \end{pmatrix}$$

- 4. Why does the order matter in matrix multiplication?
- 5. What transformation is represented by the following matrix?

$$\begin{pmatrix}
0 & -1 & 0 & 4 \\
1 & 0 & 0 & -3 \\
0 & 0 & 2 & 5 \\
0 & 0 & 0 & 1
\end{pmatrix}$$

6. In the following transformation matrix, what do the values 3, 5, and 7

D. Quizzes and Questionnaires

represent?

$$\begin{pmatrix} 3 & 0 & 0 & 0 \\ 0 & 5 & 0 & 0 \\ 0 & 0 & 7 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

7. In I3T, create the following transformation sequence:

- Scale the cube by a factor of 2 along the X axis and 0.5 along the Z axis.
- Rotate it by 45° around the Y axis.
- Translate it to the position [3, 4, 6].

Submit a screenshot showing the transformation matrices in the Workspace and the result in the Scene View.

8. How can you visualize the effect of applying transformations sequentially in I3T?

## D.1.2 Correct Answers

- $\vec{a} \cdot \vec{b} = a_x b_x + a_y b_y + a_z b_z$
- 2. The dot product indicates the cosine of the angle between the vectors. If the result is 0, the vectors are perpendicular.
- (19, 22), (43, 50)
- 4. Because matrix multiplication is not commutative. Changing the order changes the result due to how transformations are applied.
- 5. A rotation around the Z axis by  $90^{\circ}$ , followed by a translation by [4, -3, 5] and a scaling of 2 along the Z axis.
- 6. Scaling by 3 on X, 5 on Y, and 7 on Z axis.
- 7. No fixed answer. It should show TRS sequence.
- 8. Using tracking.

## D.2 Second Week Quiz

## D.2.1 Questions

- 1. Provide an example of a model transformation that is not rigid.
- 2. We have a long thin strip of paper folded zigzag to form a narrow meandering shape. If we wanted to render it using 850 triangles, how many vertices would we need in GL\_TRIANGLES mode and how many in GL\_TRIANGLE STRIP mode?
- 3. Through which coordinates does a point progressively pass during rendering in the graphics pipeline, and what transformations are applied? Write your answer in the format: coordinates → transformation → coordinates
- 4. What portion of the world (what coordinate range) will be displayed if the PVM matrix is an identity matrix?
- 5. What basic transformations compose the viewport transformation?
- 6. In I3T, demonstrate the difference between orthographic and perspective projections as clearly as possible:
  - Place at least two models in the scene
  - Use two cameras connected to two screens
  - Submit a screenshot of the Workspace section containing both screens showing the projection differences

Briefly describe your image (where the difference manifested)

7. For which projection can you tell whether an object is flying toward or away from the camera? Explain why this can be determined?

## D.2.2 Correct Answers

- 1. Non-uniform scaling (e.g., stretching along one axis).
- 2. GL TRIANGLES:  $850 \times 3 = 2550$  vertices
  - GL TRIANGLE STRIP: 850 + 2 = 852 vertices
- 3. Object space  $\rightarrow$  Model matrix  $\rightarrow$  World space  $\rightarrow$  View matrix  $\rightarrow$  Camera

### D. Quizzes and Questionnaires

- space  $\to$  Projection matrix  $\to$  Clip space  $\to$  Perspective divide  $\to$  NDC  $\to$  Viewport transform  $\to$  Screen coordinates
- 4. Only the part within coordinates [-1,1] in all three axes (X, Y, Z) will be shown.
- 5. Translation and scaling.
- 6. No fixed answer. The difference should be visible in the size/perspective distortion.
- 7. Perspective projection. Because the distance changes apparent size and depth cues appear.

# **D.3** Comprehensive Final Quiz

## D.3.1 Questions

- 1. What type of transformation does the transition matrix between two coordinate systems describe?
  - a. Translation only
  - b. Rotation only
  - c. Combination of translation and rotation
  - d. Scale change only
- 2. You have two coordinate systems: A and B. What is the correct procedure for transforming a point from system A to system B?
  - a. Use transformation matrix B directly
  - b. Use inverse matrix A and then matrix B
  - c. Multiply the point only by inverse matrix B
  - d. Convert the point to homogeneous coordinates and use identity matrix
- 3. How can we obtain axes in a new coordinate system using axes from the original coordinate system?
- 4. What causes Gimbal Lock?

- a. When two rotation axes coincide
- b. When transformation contains incorrect inverse matrix
- c. When rotation doesn't occur in global coordinate system
- d. When all angles are zero
- 5. What is the main difference between orthogonal and perspective projection in computer graphics?
  - a. In perspective projection objects remain the same size regardless of distance
  - b. In orthogonal projection distant objects appear larger than near ones
  - c. In perspective projection distant objects appear smaller based on distance
  - d. In orthogonal projection objects are distorted based on orientation

#### D.3.2 Correct Answers

- 1. (c) Combination of translation and rotation
- 2. (b) Use inverse matrix A and then matrix B
- 3. By expressing each axis of the new coordinate system as a linear combination of the original coordinate system's axes.
- 4. (a) When two rotation axes coincide
- 5. (c) In perspective projection distant objects appear smaller based on distance

# D.4 Feedback Questionnares

## D.4.1 First Week Feedback

- 1. How easy were the tutorials to understand?

  Very Easy

  1

  2

  3

  4

  5

  Very Difficult
- 2. Was the information in tutorials clearly structured?

D. Quizzes and Questionnaires					
	Yes 2.1 If no, what was unclear?		No		
3.	Was the tutorial flow logical? Logical Missing steps Steps out of ore 3.1 If something was missing or illogical, what exact		Confusing		
4.	Is the tutorial text too long, too short, or just right Too long  Too short	t?	Just right		
5.	What would improve the tutorials?  More examples More explanations More	visuals	Other:		
6.	Would tutorials be more engaging if structured as and progress tracking?	s a game	with levels		
	Yes No No preference		Other:		
7.	Would you prefer interactive elements like quizzes wire of just reading?	thin tuto	rials instead		
	Yes No No preference		Other:		
8.	Did you use the manual while completing tutorials Yes	?	No		
9.	Should the manual include links to related theory? Yes No		Other:		
10.	. Was the manual easy to navigate when you needed	l addition	nal informa-		
	tion? Yes 10.1 If no, what was difficult or confusing?		No		
	D.4.2 Final Feedback				
1.	How easily did you understand the application comessay 1 2 3 4	trols? 5	Difficult		
2.	Was the interface intuitive? Yes Partially		No		
3.		fficult an	d confusing		
4.	. How much did I3T help you understand transform	nations co	ompared to		
	pure theoretical explanation? Very helpful 1 2 3 4	5	Not at all		

- 5. Which specific part of I3T helped you understand the material most?
- 6. Which control elements caused you the most difficulty?
- 7. What would make I3T exercises more beneficial for you?
- 8. How else could I3T be used in teaching?