Using Competencies to Structure Scientific Writing Education

Aletta Nylén, Christina Dörge

Department of Information Technology
Uppsala University
Uppsala, Sweden
aletta.nylen@it.uu.se
cd@mdc.de

Abstract: Scientific writing is an important skill for computer science and computer engineering professionals. In this paper we present a writing concept across the curriculum program directed towards scientific writing. The program is built around a hierarchy of learning outcomes. The hierarchy is constructed through analyzing the learning outcomes in relation to competencies that are needed to fulfill them.

1 Introduction

An important part of educating Computer Science and IT engineering students is to ensure that they develop the skills that are necessary for their future profession. According to the U.S. Bureau of Labour Statistics, important qualities in software developers, engineers and computer science research scientists are not only creativity, analytical skills and problem solving, but also team work and communication skills [BLS]. Writing skills are needed to communicate with other professionals, with or without a computer science or engineering background. Researchers and developers need to be able to communicate their conclusions to people without technical background and to write for academic journals, etc.

The American Computing and Accreditation Commission (ABET) states that students of computing programs should gain *"(f) An ability to communicate effectively with a range of audiences"* (see [ABET11a], p. 3). For engineering programs (see [ABET11b], p. 3), the corresponding student outcomes are expressed as *"(g) an ability to communicate effectively"* and *"(d) an ability to function on multidisciplinary teams."* Obviously, writing is an important issue in educational programs, but what is done to help students fulfill these outcomes, to gain the necessary professional skills?

Many teachers regard teaching their subject as their primary task and do neither teach nor comment on how the students present their work and in particular, on how the students write. Previous literature [Kay98, Gar10] report that CS faculty hesitate to grade

writing since they do not have language expertise and since they consider evaluating writing to be a tedious task. Ironically, the very same teachers often complain about the students having insufficient language and writing skills when they are about to write their thesis by the end of the education. Some efforts are made to improve the situation, e.g., by introducing writing assignments in courses, but the impact of isolated efforts of this kind seems to be limited, especially since it is more often than not that the students do not get the feedback they need to progress.

At Uppsala University (UU/IT), we are implementing a program to improve the scientific writing skills in CS major and IT engineering students. The program builds on ideas from the Writing Across the Curriculum (WAC) movement, in particular from the branch Writing Within the Discipline (WID), in that it incorporates writing training in regular computer science courses throughout the education [WAC]. The benefits of this approach is described by Carpenter and Krest [CK01] as *"WID extends WAC in that both WID and WAC help students to think critically about disciplinary content; but WID also helps students to develop their writing skills as they articulate their understanding of content in genres appropriate to professional audiences."*

In this paper, we present the program and, in particular, how we have formulated learning outcomes for the writing at different levels of studies. The learning outcomes serve as a structure, both for teachers and for students, for achieving progression in the quality of student writing as well as in writing assignments and the way they are graded. We will discuss these goals in relation with the competency debate and in relation to other work in the area to underlay the argumentation for the approach. The structure presented here can be adapted to writing in other branches of science and the framework for working with such structures can be used for other professional competencies, e.g., working in teams or oral communication.

2 Brief description of the writing program

The program aims at improving the scientific writing skills of CS and IT Engineering students. We adopt the definition of scientific writing as *"specific types of documents that scientists typically write and read in their professional work"* from [CK01]. This means that the goal of the project is to prepare the students for their coming professional life, but this does not in any way exclude engagement in other forms of student writing during the education and within the program [Gar10].

Currently, we focus on the BSc level, which, at UU, is the first three years of the students' university education. The goal is that, by the end of these three years, the students should be able to write at the level of a Bachelor thesis. The program builds on the following principles:

Frequent writing training. In a study by Hawthorne [Haw98], students express that being exposed to different writing assignments throughout their studies has improved their writing skills.

Writing training within the subject. Hooper and Butler conclude that skills achieved in a general writing course are not necessarily transferred to writing in other disciplines [HB08]. Writing is, in addition to being a way of communication, also a way of learning [Emi88] and it helps to form the professional identity [CK01]. If writing training is not performed within the discipline, these advantages will be lost.

Instructions and feedback. Moore concludes that without proper instructions, guidance and feedback, the only effect of writing assignments is to reinforce bad writing [Moo93]. He also argues that with proper guidance, students show significant improvements both in writing skills and in content knowledge.

Progression goals. We believe that it is not only important that students practice writing regularly and that they get feedback: in order for the students to continue progressing over time, it is important that the level of writing required in assignments increases as the students mature as writers. The feedback should also meet students at their current level and promote further development.

In practice, the students will have at least two courses per year with assignments where writing is graded. These assignments are within regular computer science courses. The type of assignment and how it is graded is directed by the goals for the course level. The program offers support for teachers when it comes to making assignment instructions, material on how to write and grading the writing. The university's writing center supports the program by giving instruction lectures and support to students working with the assignments. We have chosen to work with teachers that are interested in using this framework within their courses and for those courses, the syllabus have been changed to ensure that writing skills are part of the course goals.

3 Level dependent learning outcomes

A core part in the implementation of the program is to formulate intended learning outcomes (ILOs) or progression goals for different levels of the education. We have chosen to use the same levels as are used for the courses at Uppsala University. ILOs have been formulated for four different levels leading up to the Bachelor Degree. The levels are presented in Table 1. In a similar way, there are three additional levels leading up to the MSc Degree, but they are not covered in this work.

G1N	Beginners, first course
G1F	Advanced beginners course, first and second year of studies
G2F	Continuing courses up to the Bachelor level, second and third year of studies
G2E	Bachelor Thesis

Table 1: Course levels at Uppsala University.

The ILOs are additive, meaning that in addition to meeting the ILOs of the level a student is currently at, he or she should also meet the ILOs of all lower levels. A student meeting all ILOs for these four levels should be able to write well enough for a BSc Thesis in computer science at Uppsala University.

Sometimes, a student may attend a course at a higher level before meeting all of the writing goals at lower levels. This can happen because the student has not yet completed all previous courses or because he or she chooses to take courses in a different order than expected. This is not a problem, however, since the goals are additive, which means that all previous levels are also examined.

When teaching scientific writing in higher education, we can assume that the students already have some basic skills such as general language skills, the ability to write some types of texts in their first language, etc.[1] The program aims at further improving these basic writing skills as well as extending them by adding both general academic writing skills and more discipline specific style and jargon. We have used "Writing for Computer Science" [Zob04] as a basis when formulating our ILOs.

3.1 Intended learning outcomes

The intended learning outcomes for the different course levels are:

G1N – Beginners, first course

You should be able to

1. identify different types of text in the field and describe their structure;
2. write a text that reproduces information from other sources;
3. write a text that is suitable[2] for the intended reader[3];
4. write a text that has a clear theme and is appealing[4] to the intended reader;
5. write text that is linguistically correct regarding spelling, paragraphing punctuation, etc.;
6. use references and citations correctly;
7. discuss what information is necessary and what information is sufficient for a text.

[1] These high school level skills correspond to the learning outcomes for level G1N.
[2] A text that is *suitable* for the reader is a text that the reader can understand.
[3] Students are required to be able to write for different audiences, e.g., both for readers (at least) as knowledgeable in science and technology as the students themselves and for readers who do not know anything about the subject.
[4] A text that is *appealing* is a text that the reader can both understand and enjoy.

G1F – First and second year

You should be able to

1. provide constructive feedback on the work of others with the help of checklists;
2. write summaries of simple scientific articles;
3. describe and evaluate your own work in writing, e.g., lab report. The report should have a good structure;
4. apply principles of necessary and sufficient information in your own texts.

G2F – Second and third year

You should be able to

1. give constructive feedback[5] on the work of others;
2. describe and evaluate larger projects in writing. A special focus is on selection of appropriate[6] levels of abstraction in different parts of the text;
3. use figures and diagrams in a proper manner;
4. produce "well-prepared"[7] text in Swedish[8];
5. write original text in English.

G2E – Bachelor Thesis

This level is the final stage of the BSc education. At this level the students should have reached all goals from the previous levels, and should be able to show this by writing a BSc thesis.

4 Relation between the ILOs and developing competencies

The aim of the program is to help students develop into competent professionals, in particular when it comes to writing. In his speech at the "Modeling and Measurement of

[5] Praise and criticism that can be used to improve the work, that is not impolite or offensive or driven by any negative emotional motivation.
[6] The level of detail should be necessary and sufficient in the given context.
[7] The paper should show signs of a good elaborated work, not only in terms of scientific aspects, but also in terms of insight, the information chosen, and the structure.
[8] Swedish is assumed to be the students' first language. Students at the MSc level should write well in both Swedish and English.

Competencies in Higher Education" conference (Berlin, 2011), D. Royce Sadler gave a good description of the relation between competence and competency [Sad11]:

> *[These two terms] are usually used synonymously, but their subtle distinction lies in potential versus actual ability. In other words, competence as a generalised characteristic vs. demonstrated skill in performing an actual task in the area where one has this potential. [...] Use of the term competency for a discrete knowledge element or skill invites the plural form competencies to mean a collection of competencies. The use of competency as both an 'envelope' and an 'elemental' term can lead to confusion. The term competence is, admittedly, less common but it is still intuitively easy to understand.*

We interpret this as that in order to educate students to become competent professionals, have competence (potential ability), we need to help them develop the competency (actual abilities) that can, in the end, be combined to achieve competence. It is therefore relevant to examine what competencies need to be developed to achieve the ILOs described in Section 3.

We refer to OECD ([OECD], p. 4) for a definition of a competency:

> *A competency is more than just knowledge and skills. It involves the ability to meet complex demands, by drawing on and mobilising psychosocial resources (including skills and attitudes) in a particular context.*

For this work, it is sufficient to define a competency as

$$\text{Competency} = \text{knowledge} + \text{skill} + \text{motivation}$$

We adopt a categorization of competencies into social, personal and methodical competencies as described by Dörge [Dör10]. This approach is often used in the German discussion about competencies.

4.1 Concept Map

We have analyzed what competencies and knowledge are needed to achieve each ILO (described in section 3). Some ILOs are achieved by further development of other, less advanced, ILOs. The result is structured and visualized in a concept map, which contains the ILOs, competencies and knowledge we believe are developed or used to fulfill the ILOs up to the level of the map.

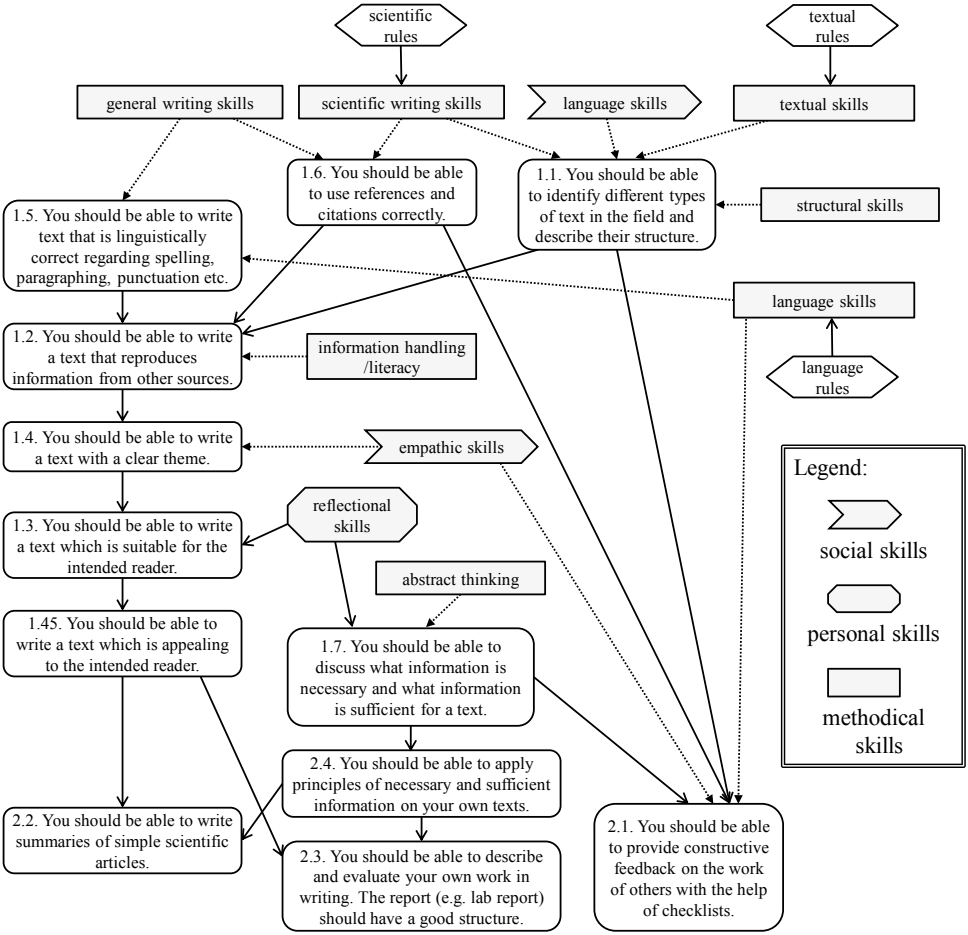

Figure 1: Learning outcomes for the levels G1N and G1F and their relation to competencies

Figure 1 shows the concept map for levels G1N and G1F. For each ILO, it illustrates which competencies, knowledge and other ILOs it builds on. This relation is shown by arrows pointing from the basis, ILOs, competencies and knowledge, to more advanced ILOs. For simplicity, competencies that are developed in several ILOs that build on each other have only been included once.

Competencies are divided into three main categories: social (marked by arrow shape), personal (octagon shaped) and methodical competencies (rectangle shaped). Special knowledge areas are illustrated by hexagons.

The concept map illustrates how the ILOs can be used to break down program outcomes, such as those defined by ABET and described in Section 1, to the competencies and knowledge they are based on. It provides a structure, showing in what way different ILOs build on each other and how the complexity increases when several ILOs and competencies form the basis for more advanced ILOs. This structure is a support in the

process of deciding the order in which the ILOs should be emphasized in the education, i.e., in what level they should appear. The concept map is also an aid in gaining an understanding of what competencies we need to develop to achieve certain outcomes.

4.2 Competencies and knowledge in scientific writing

A according to our concept map, the following competencies and skills provide the foundation for the writing ILOs:

- **language skills (method):** to use a specific language to describe things
- **information handling / literacy (method):** to obtain and process information
- **general writing skills (method):** to write text which is understandable and has a meaning
- **scientific writing skills (method):** more specified than "general writing skills" (see Section 2 for a definition of scientific writing)
- **structural skills (method):** to structure material (e.g. information) for a given task
- **textual skills (method):** related to *structural skills*, but refers only to the structure of text, e.g., the structures of different types of texts
- **abstract thinking (method):** to sort out which parts of information are relevant and interesting in a given context and to find the appropriate granularity for presenting the information

- **languages skills (social):** how to use a specific language to address people
- **empathic skills (social):** to be aware of what the reader might expect or understand when reading the text

- **reflectional skills (personal):** to be able to understand what a certain behavior or action will result in

We have also included knowledge items in the concept map. For a definition of knowledge see for example ([GMS+92], p. 724, col. 1):

> *1. the facts or experiences known by a person or group of people. 2. the state of knowing. 3. consciousness or familiarity gained by experience or learning. 4. erudition or informed learning. 5. specific information about a subject.*

The knowledge items used in Figure 1 are:

- **textual rules:** formatting rules, layout, structural aspects like header, section, chapter
- **scientific rules:** how to cite, how to use references correctly in the text, when to use a reference
- **language rules:** words, semantics, inter-punctuation

5 Comparing the writing course hierarchy to the SOLO-taxonomy

The hierarchical structure of our writing ILOs is invented and designed to fit the course level structure at Uppsala University. The course concept was developed as an isolated construct and not derived from an already established framework so it needs to be evaluated. Since competencies are already a part of our construct, we have chosen to evaluate it by contrasting it to an established taxonomy of competencies, the SOLO-taxonomy [CB82,BT11].

SOLO, which stands for "Structure of the Observed Learning Outcomes, was chosen because it provides a scheme to evaluate our structure through the verbs used to describe the different ILOs. "*The verb in the ILO has two main functions: it says what the student is to be able to do with the topic and at what level*" [BT11], p. 123.

unistructural	memorize, identify, recognize, count, define, draw, find, label, match, name, quote, recall, recite, order, tell, write, imitate
multistructural	classify, describe, list, report, discuss, illustrate, select, narrate, compute, sequence, outline, separate
relational	apply, integrate, analyze, explain, predict, conclude, summarize, review, argue, transfer, make a plan, characterize, compare, contrast, review and rewrite, examine, translate, paraphrase, solve a problem
extended abstract	theorize, hypothesize, generalize, reflect, generate, create, compose, invent, originate, prove from first principles, make an original case, solve from first principles

Table 2: SOLO-levels

The taxonomy defines four different levels. Biggs and Tang list a number of verbs suitable for ILOs at each level. Table 2, from Biggs and Tangs book "Teaching for Quality Learning at University" [BT11], p.123, lists the levels together with verbs, from the lowest to the highest level.

5.1 Result of the Comparison

For each ILO, the verbs have been marked and classified according to Table 2.

G1N – Beginners, first course

You should be able to

1. **identify (unistructural)** different types of text in the field and **describe (multistructural)** their structure;

2. **write a text which reproduces the information (unistructural)** from other sources;

3. **write a text which is suitable for the intended audience (relational**, requires you to predict**)**;

4. **write (unistructural)** a text, which has a **clear theme (multistructural**, requires you to sequence**)** and **is appealing to the intended reader (relational)**;

5. **write (unistructural)** text that is linguistically correct regarding spelling, paragraphing, punctuation, etc.

6. use references and citations correctly (**unistructural**);

7. **discuss (multistructural)** what information is required and what information is sufficient for a text.

G1F – First and second year

You should be able to

1. **provide constructive feedback** on the work of others **with the help of checklists (relational**, requires you to compare/contrast**);**

2. **write summaries (unistructural)** of simple scientific articles;

3. **describe (multistructural)** and **evaluate (relational**, requires you to compare**)** your own work in writing, e.g., lab report. The report should have a good structure.;

4. **apply (relational)** principles of necessary and sufficient information in your own texts.

G2F – Second and third year

You should be able to

1. **give constructive feedback (relational and extended abstract**, requires you to compare and reflect**)** on the work of others;

2. **describe (multistructural)** and **evaluate (relational**, requires you to compare**)** larger projects in writing. A special focus is on selection of appropriate levels of abstraction in different parts of the text;

3. **use figures and diagrams (multistructural**, requires you to illustrate**)** in a proper manner.

4. You should be able to **produce "well-prepared" text (relational**, requires you to rewrite and paraphrase**)** in Swedish.

5. You must be able to **write** original text in English. (**This one is not unistructural, because the students aren't English natives.**)

Most ILOs at the G1N level are uni- or multistructural according to the SOLO taxonomy. This is well in line with the intended course level. However, two of the ILOs are relational: those including a prediction of how a text is received by different audiences. In the early stages of the education, when the students are themselves novices, the different audiences will in practice range from novices to almost novices, simplifying the goal. As the students progress, the range of possible audiences will expand towards experts and the goal will become more complex.

Looking at the higher levels, more relational ILOs appear. At the G2F level, extended abstract ILOs are added indicating that the SOLO level is raised even further. It can be argued that the structure of the course concept is well designed according to the definition of ILOs of the SOLO taxonomy by Biggs and Tang [BT11].

6 Conclusions

Being able to communicate efficiently in writing, both with professionals in the same field and with others, is essential to CS and IT engineering professionals. Therefore, we need to provide structured writing education to help students develop these writing skills. We have presented a WAC program built on a structure consisting of progressing learning outcomes for writing. One of the basic goals has been to develop the structure in such a way that competencies, skills and knowledge achieved at one level are the foundation for the next level of courses. It thus forms a hierarchy of learning outcomes. This hierarchy conforms to the levels of the well-established SOLO taxonomy.

This work is also an example of how competence models can be designed, used and evaluated by contrasting it to established taxonomies. The model designed in this work has served as an aid in structuring the ILOs. It has also contributed to our own understanding of what it takes for a student to fulfill each ILO, what competencies need to be developed. This knowledge helps in our teaching by allowing us to direct teaching activities and feedback towards the needed competency development rather than its manifestation, the poorly written text.

The program, and hence also the structure, is designed for CS and IT engineering students and the type of writing that they need to learn, but can, with adaptations, also be used for other branches of scientific writing and possibly even for writing in other subjects. An interesting direction of further research is to adopt the general framework used in this work to create competence models and programs for development of other professional skills such as oral communication or group working skills.

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