Learning by Teaching: Professional Skills and New Technologies for University Education

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The authors present a teaching methodology that teaches students the art of teaching. Students learn how to communicate technical content efficiently in lecture, self-learning, and teamwork settings. Students work with constructive alignment and active listening. In addition, they learn how to assess self-learning training materials systematically, and how to give constructive feedback.

Abstract

Besides technical skills, industry increasingly demands professional skills. Teaching these at university is challenging and still rare. In computer science, new technologies and relevant tools emerge quickly. Keeping curricula up to date is challenging. We present a teaching methodology that teaches students the art of teaching. Students learn how to communicate technical content efficiently in lecture, self-learning, and teamwork settings. Students work with constructive alignment and active listening. In addition, they learn how to assess self-learning training materials systematically, and how to give constructive feedback. Finally, they access a technical topic from a new dimension by practically teaching it. During the course, the students train the described skills under guidance by developing new exercises. The article presents our course unit that teaches important professional skills and produces a continuous stream of new teaching material, which is integrated into class. The unit enables teaching relevant and new technologies early. The presented methodology has been continuously applied at the Technical University of Munich since 2013. Through 2019, more than 150 students have participated. More than 60 new exercises were created. A structured evaluation shows the power of the approach.

Motivation

In computer science (CS), technology is changing fast. Industry not only demands fundamental knowledge but expects graduates to also bring experience in recent mechanisms and tools [1]. Current examples are distributed ledgers and blockchain, the Internet of Things, and machine learning. In addition to the demand, students are highly motivated to learn about cutting edge technologies. Including new technologies into the curriculum quickly is therefore beneficial.

Today, companies expect not only technical hard skills but also so-called professional skills [1–3]. Professional skills include communication, project management, conflict management, diversity management, and teamwork, with tools such as active listening, constructive alignment, and constructive feedback [2, 4–6].

For teachers, both are challenging: integrating new technologies into their curriculum and teaching students professional skills. This article presents a teaching methodology that enables students to create high-quality teaching materials on recent CS topics while practicing professional skills. The methodology provides the necessary didactical background, suitable tools for the creation of new exercise material, and knowledge of and direct experimentation with relevant professional skills. The methodology is continuously applied as one unit of the iLab course series at the Technical University of Munich (TUM) [7]. This unit is called Create Your Own Exercise (CYO — "See, yo!").

The presented methodology covers relevant aspects for various sciences and humanities. It can be applied directly to other disciplines besides CS. Regarding the tooling, students only have to be able to work with web tools such as Wikis. In addition, students should either have prior knowledge in the target domain, or be able and eager to get such knowledge in a reasonable timeframe. For our graduate students, this is the case.

The presented methodology has been running continuously at TUM since 2013. Through 2019, more than 150 students have successfully participated, resulting in more than 60 new technical exercises.

The next section discusses the relation to the state of the art. We present the setting of the unit. A detailed presentation of the teaching methodology follows. We assess the effects of the methodology with quantitative and qualitative evaluations.

Related Work

There is a body of related works. They emphasize the importance of having professional skills in technical professions on one hand, and on the other hand identify a lack of suitable methodologies for teaching them. The same applies to the inclusion of technologies early in the curricula. This article presents a solution that addresses both challenges symbiotically. We are not aware of similar existing approaches.

In [2, 8, 9] the authors emphasize the crucial role of professional skills in technical curricula and professional work. They find that professional skills are often underrepresented in today's curricula, even including the meta-curricula provided by IEEE and ACM [10, 11].

The authors of [3, 12] confirm the industrial need for professional skills training at university. Their assessment is based on different factors including a systematic analysis of job offers [3] and surveys with companies employing former graduates [12]. The presented CYO unit contrib-

Digital Object Identifier: 10.1109/MCOM.001.1900248

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utes a significant share to the professional skill education at TUM. The perceived improvement of skills in our evaluation confirms this.

The authors of [1] present a meta study on "the future of the curriculum in the digital age." They confirm the importance of professional skills. In addition, they identify including new technologies quickly into the curriculum as highly relevant to industry.

Setting

The Create Your Own Exercise (CYO) course unit is part of the iLab^2 course at TUM. The iLab is an elective course series that teaches around 75 students computer networks and distributed systems topics every semester (https://ilabxp.com/).

All iLab courses follow the iLab teaching methodology [7]. It is the enabler for the presented CYO. It provides the structure that enables the students to create high-quality teaching material in the given short time.

The iLab concept [7] structures each learning unit into the following parts:
1. Lecture
2. Theoretical preparation (PreLab)
3. Practical hands-on (Lab)
4. Oral attestation

With this quadruple, the iLab concept supports students optimally in their self-learning.

CYO students create parts 1–3 for a topic of their choice within 6 weeks. The CYO block is the biggest teaching unit within iLab^2. It takes place after the students have learned about topics such as IPv6, BGP, the Internet of Things, and security.

Different from the standard iLab concept [7], CYO consists of multiple lectures that have lots of interactive parts. The guiding material includes slide and exercise templates. They are provided over the eLearning lab system, which is tailored for the iLab methodology [13], making exercise creation very efficient. A video that explains the authoring of teaching content with the labsystem can be found at https://future-iot.org/cyo.

Create Your Own

CYO is a meta-circular iLab course unit: it teaches how to create iLab exercises, so-called *labs*. The students create a small exercise on a technical topic on their own, a so-called *minilab*. Raphael's masterpiece "The School of Athens" in Fig. 1 depicts CYO very well: talents meet and exchange to improve their skills and create little masterpieces under detailed expert guidance.

The minilab contains all parts of a lab to a limited extent [7]:
- A 15-minute lecture, giving the context and introducing important mechanisms and the hands-on part
- A ~7-page eLearning part for individual self-preparation, featuring a more detailed background and introducing the tools for the practical hands-on (PreLab)
- A ~10-page eLearning part for the team hands-on in the physical lab environment (Lab)

Following the iLab credo that solid preparation from the teacher side leads to better and more results [7], CYO provides clear guidance and prepared templates. The CYO unit is structured into different phases, as shown in Fig. 2.

Figure 1. Raffaello Sanzio da Urbino, Scuola di Atene, Apostolic Palace, Vatican.

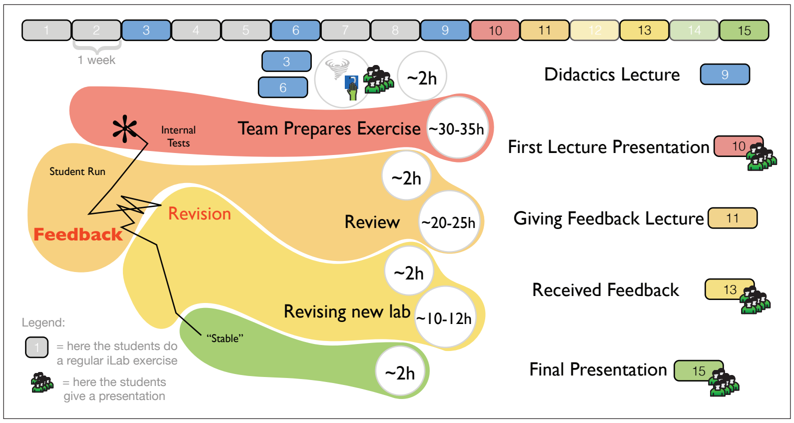

Figure 2. Phases of Create Your Own Exercise.

The left side of Fig. 2 shows the life cycle of an iLab exercise [7]: creation, review, improvement, and (ideally) a stable exercise. The circles in the middle show the times the students are expected to invest per phase. The right side of the figure shows where the students get input and where they present something as indicated by the group symbol. The numbers on top and at the lectures are the weeks of the iLab course in which the respective activities happen.

Topic Storm

The *topic storm* in week 3 starts CYO. This session introduces the umbrella topic (e.g., the Internet of Things). An umbrella topic makes all students work in the same area, which helps in understanding and supporting each other better.

For illustration, the students get a pitch example based on a real topic proposal. Then they think 5 minutes about one topic each, write it on a card, and pitch it in class.

Although spontaneous for the students, this works incredibly well. For the students it is the perfect chance to select a topic that they always wanted to look at in detail, talk about, or show their expertise in.

This phase targets inspiring all students regarding possible topics. None of the presented topics has to be chosen. Other topics can be pitched in the next round. In addition, it is possible to

The central element of the iLab concept is constructive alignment [5, 7]: the identification and clear formulation of learning goals, and the optimal adaptation of the teaching methods to them. Constructive alignment is very important in the iLab since it is partly a distant learning setting (PreLab). Distant learning requires especially well-designed material to keep the learners motivated and focused.

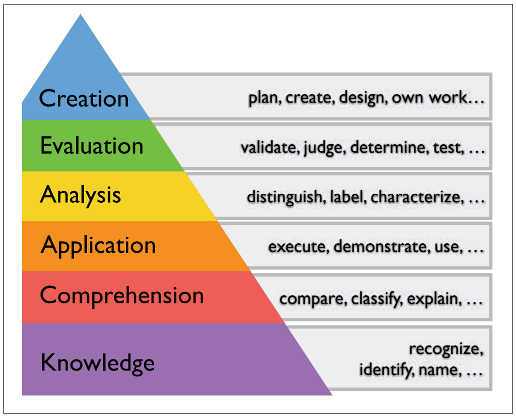

Figure 3. Teaching taxonomy steps after Bloom.

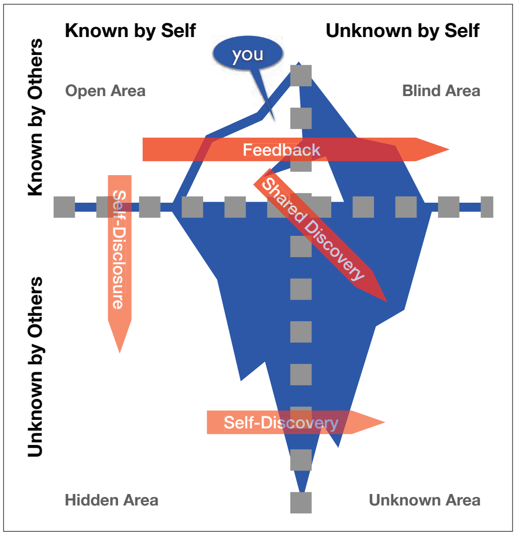

Figure 4. Role of the JoHari Window for the self and the minilab.

choose a topic another student presented. To set the stage, we give the students feedback on their topics, how suitable we consider them for our course for which reason, and how we suggest to improve them.

In the following weeks, the students have time to decide on one suitable topic each. As guidelines we tell them their topic should be interesting, concise, and explorative, and have a scientific component. Based on a slide template that provides the structure, each student prepares one topic for a longer 3 min pitch in the next phase.

Topic Voting Event

The *topic voting* lecture happens in week 6. The students present their prepared topics in 3 minutes. The goal for the students is to convince all others with their presentation that their topic is the best for CYO. In iLabs, students are paired into teams [7]. Both team members compete on which topic they will prepare together in the main CYO phase.

The audience votes after each team's two presentations which topic they consider more suitable and interesting. The winning topic is the one this team will work on. The gamification of the pitch with the voting helps improve student motivation significantly. The competition increases the presentation quality.

The lecture ends with experienced instructors giving feedback on points that are relevant for all teams such as focusing on the most important content only, or considering specific aspects in particular. Here, the students also get a clear task description for the loose shaping of their minilab exercises in the upcoming weeks.

In the aftermath of the lecture, each team gets written individual feedback to guide their planned minilab in the right direction, especially regarding focus and depth. In the upcoming weeks, while working on the other regular exercises, the students loosely think about structuring their exercises, and start exploring possible setups and tools. The CYO block part starts in week 9 with a lecture on didactics.

Didactics Lecture

The focus in the previous phases was on finding topics. Now, the students get input on the methodology and tools that enable them to create high-quality teaching material.

The *didactics lecture* introduces the students to the iLab concept [7]. Through the previous exercises, all know the concept from the consumer perspective already. To successfully apply it also from the exercise designer perspective, they get more details. They especially learn about the roles of lecture, PreLab, and Lab, and about the interplay between the iLab concept and the eLearning platform [13].

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As a tool for constructive alignment, the students learn about Bloom's teaching taxonomy [14]. Figure 3 gives an overview of the taxonomy levels combined with typical verbs that can be used to formulate a corresponding student task for reaching the according learning goal. The students learn to identify and efficiently use the taxonomy levels for their minilabs.

Key didactical elements of the iLab concept are:

- *Redundancy*: Cover important learning content in different exercise parts, providing different access, using different teaching methods.
- *Distribution of Content*: Distribute content in digestible pieces over the labsystem's virtual pages in different learning elements [13].
- *Multiple-Choice Questions*: Stimulate and guide your learner in the distant self-learning phase PreLab with well-designed multiple-choice questions. Most challenging here, besides formulating good questions, is formulating good false answer options. Ideally those options should contain common errors to stimulate critical thinking about them. Learners have three attempts, enabling explorative learning — challenging questions are allowed!

- *No Cooking-Recipe*: In the team part of the minilab, the learners get instructions and inline challenges that they have to solve [7] via *free text input fields*. The challenges should be the opposite of a cooking recipe, which is typically "copied and pasted": they should be stimulating, motivating, and challenging while remaining clear. A proposed proceeding is creating tutorial style exercises first and replacing some instructions by questions later.
- *Formulating Expectations*: Following the constructive alignment, the students should always be aware of their learning goals. To foster this, they have to formulate example solutions and distribute 30 credits over their minilab to weight their exercise parts to each other.
- *Story Telling*: Embedding tasks in a story, such as being the company responsible for task XY when an incident happens, provides additional motivation and structure for the learners.
- *Being concise and precise*: Formulating background information, instructions, and questions in a concise and precise way is an art. The lecture provides examples and training.
- *Test, test, test*: As the life cycle in Fig. 2 shows, testing is the key to success. The students learn about the importance of testing their content over and over again.
- *Tooling*: The eLearning system [13] is designed to support course authors that implement the iLab concept [7]. After a short introduction, the students can efficiently start their minilab creation. An example video of such a creation is here: https://future-iot.org/cyo.

The didactics lecture raises awareness that good teaching material is not magic but solid work, similar to writing computer programs. Even though the concepts might seem unfamiliar at first, their deep embedding in all provided templates and tools makes their application straightforward and easy. This is important for reaching the ultimate goal of the iLab concept: a learner's satisfaction by seeing the high quality of their self-created artifacts [7].

The didactics crash course leads to significantly better exercises. It is the kick-off to each team's hot phase of preparing the first version of their minilab.

Preparation of First Version

In weeks 9–12 the teams prepare the first version of their minilabs. The next milestone is giving the first version of their minilab lecture to the class in week 10.

As in all other exercises following the iLab concept [7], the teams work mostly on their own and support each other directly. This reduces the instructor workload significantly. In contrast to the rest of the iLabs, where both team members work together on the same issues, in CYO the team members should work in parallel on different subtopics and synchronize to speed up the development. The resulting self- and team management are desired learning goals. The detailed templates for lecture, prelab, and lab with examples and pre-structuring give guidance and help focusing on the goal [7]: creating a good minilab. The teams work on all three parts in parallel. For the introductory lecture, the students need a clear picture of their entire exercise, although not everything has to be finished to hold the lecture. In the lecture preparation the students extend their initial pitch slides to 15 minutes.

First Lecture

In the first lecture the students present their learning goals, give the context of their exercise, introduce concepts, mechanisms, and tools required for their hands-on, and tease the practical part.

The first lecture version does not have to be perfect. Its goal is to make the students aware of each other's ideas and progress. The teams should learn interesting aspects from each other (Fig. 1). As a result, good teams are happy to see positive reception of their content. Teams with lower exercise quality profit from seeing good examples and getting motivated to improve their content.

Besides the content, another focus of the first lecture is on the presentation style. The students get input on relevant presentation aspects including used teaching methods, visual and aural appearance, and interaction. Each student takes notes on a prepared sheet. After all presentations, the students collect their most important points on the board. The resulting common issues checklist helps everybody for the next presentations.

After the lectures, all students know all topics. Each team gets a review partner team. Using the lab system, the teams indicate their preferences regarding the review. The best match is calculated. As a result, a team is typically not *mutually* paired with its review team.

After the presentations, the instructors also give detailed individual feedback through the lab system on each presentation with a focus on the content. Now the students have two more weeks to include the feedback, and to finish their PreLab and Lab parts.

Giving Good Feedback

Good feedback is extremely valuable. The next lecture is about giving good feedback and successfully receiving feedback. The survey reveals that the students bring a strong background here already. However, they still find it helpful to get a compact summary of relevant considerations and aspects.

The *Johari window* [15] motivates the role and power of feedback. It divides the self into four areas that are known or unknown by oneself or others (Fig. 4).

Feedback helps discover aspects one does not know about oneself. This unknown includes parts revealed in the student's teacher role. In addition, the iceberg in Fig. 4 stands for the minlab. Through feedback, the students can improve their minilabs in aspects they did not consider before.

Next, the students learn about *constructive feedback* [6]. Constructive feedback is information-specific, issue-focused, and based on observations (not interpretations). As tool for giving constructive easily digested feedback, the POWWER burger represents an easily memorized recipe: "POsitive basis," "What did I observe?," "What was my impression?," "What is my wish?," "Expected Result?"

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The review phase teaches the students to assess technical content. It improves the minilab quality significantly. The provided assessment criteria apply to the reviewer's creation as well. It is easier to see someone else's mistakes. Therefore, through reviewing others, the students can apply the review criteria better to their own creations.

Finally, the students learn about active listening and suitable feedback processing. The feedback toolset equips the students for reviewing and being reviewed.

To foster project management and learning from each other, the feedback lecture ends with a collection of individually open issues for lecture, PreLab, and Lab.

The following week is for implementing the remaining issues and thoroughly testing the exercises. Tests are very important to identify open issues that can be found by the team themselves before using the capacity of the reviewers to identify the self-hidden part of the iceberg in Fig. 4. The next phase is meeting with the reviewing teams.

Review

The review is a thorough test of the exercises. It consists of a cognitive walk-through. The review team does the new minilab like a regular exercise, and writes down the experiences and improvement suggestions.

For the hands-on Lab, the creators sit behind the reviewers in the lab room and watch them do their minilab. The creators should not give the reviewers help or input, but watch silently. The students particularly like this eye-opening experience. Watching is important to see issues first hand. It increases the minilab quality significantly.

After completing the Lab, the review team communicates their findings to the creators. Those take notes and receive the reviewers' assessment report. This report is also handed in for grading over the lab system. The creators start improving their minilab according to the feedback, as shown in phases 2 and 3 in Fig. 2.

In CYO, the students get to know the full instructor perspective. In the end of the CYO part, the reviewers complete their experience by creating an assessment report over the entire reviewed minilab. It includes the second version of the lecture and the improvements in PreLab and Lab. The students also give credits on the assessed team's creations.

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For the upcoming week, the students prepare a report about their review experience.

Received Feedback Presentations

In week 13, the students report on the *received feedback*. Based on the received input, they present a plan to improve their exercises over the remaining days toward an excellent minilab. In this presentation the students also present their online material to the class. They scroll through it on the projector and explain it. The teams close with a report about their reviewer experience. Their reviewed team continues.

During the presentations, the students in the audience note the most important improvement suggestions they hear. The later collection on the board results in a good overview of common points that all teams should check once again.

Typical issues that are revealed are imprecise instructions and questions, and too much content for the 1.5 h timeframe. The students get mitigation strategies at hand, such as providing more partial solutions in their minilab to make its completion faster.

A major goal of the review presentation is fostering critical discussion of the review feedback within the teams. Another goal is making the review teams check if their feedback was well understood, and to give additional hints if not.

Improvement

Based on their own improvement plan, and inspired by the reports of the other teams, the students use weeks 14–15 to improve their minilabs. A motivating factor is that minlabs with high enough quality will be offered for future students with the creators being named as authors.

In addition, the reviewing teams assess the updates once again to see how good the exercises are now. Finally, the instructor's assessment of the created content is the biggest portion of the mark for CYO.

Final Lecture

CYO ends with the second presentation of the lecture. Typically, the lectures have significantly improved since the students have much more experience in didactics now, have implemented the feedback, and have the entire exercise ready. All students have heard all content now at least three times via lecture versions 1 and 2, and the review presentation walk-through.

Evaluation

CYO provides:

1. Teaching professional skills
2. Teaching hard skills (technical minilab contents and creation of good training material)
3. Including new technologies into the curriculum regularly and early

This section discusses how the proposed methodology reaches these goals and evaluates how well it succeeds. For the evaluation, 59 former students participated in an online survey. The percentages given are the average values of all 59 responses.

Overall, CYO is very well received by the participants. 86 percent liked or even loved taking part in CYO. 90 percent would recommend taking part to their friends. More than 3/4 of the survey participants found the professional skills useful or very useful for their professional lives.

The technical knowledge gain is very good, especially for the own creations. 64 percent found CYO even better for learning technical content than learning with the already given exercises. This is not surprising as teaching is even more intense working with the learning content.

Professional Skills

CYO teaches several important professional skills that were also identified by the related work. The students train their *communication skills* in *different settings*: individual communication within the teams, group communication between the teams such as in the review phase, and lecture settings where both team partners present in front of the group.

The communication covers both *technical and non-technical topics*. Various *presentation skills* are trained including slides for the lectures, texts, quizzes, and free text questions for the eLearning content, structured feedback in the reviews, data collections on boards, and question sheets.

The students not only train their skills but actively reflect over them in the different feedback-on-the-board sessions. Communication techniques that are especially trained are *giving and receiving feedback*.

Regarding *project management*, the students have lots of tools and structures at hand. These guarantee that the teams reach the minimal goal. However, better teams use the opportunity to experiment with different project management techniques to reach their goal of having an excellent minilab. The teams train self-responsibility, control, leadership, and commitment within their team and among all teams.

The students train their *interpersonal skills* in different constellations. This includes self-awareness (Fig. 4), social awareness, and teamwork. It also includes *conflict management* first of all within the teams: competition around the better perceived topic, and decisions on directing the exercise creation, meeting deadlines, and so on. Coping with *diversity* is an important skill that is trained in CYO. The iLabs traditionally have multi-cultural participants since the beginning as they run in English. Different cultural backgrounds bring different working styles. This becomes very obvious in CYO. The students so far have always managed it very well and taken the best from it.

The perceived *ability to teach content* climbed from 56 to 76 percent expertise through CYO. The lecturing skills increased from 19 to 75 percent expertise. The self-learning material creation skills (PreLab) increased from 33 to 74 percent expertise. The hands-on material preparation skills increased from 36 percent to 75 percent.

Expertise in *reviewing material* climbed from 13 to 73 percent, *giving feedback skills* 16 to 76 percent expertise, *receiving feedback skills* 10 to 78 percent. Finally, the expertise in *constructive alignment* increased from 28 to 72 percent.

The final experience level self-assessments are around 75 percent. This is not surprising as the knowledge and techniques around the professional skills were not trained much before, and are probably perceived as even more trained through practical professional experience years later. The high increases support this interpretation (Fig. 5).

The students already bring good knowledge in giving and receiving feedback. The on-site collection of pre-knowledge confirms this. Therefore, the least increase is perceived in these domains.

85 percent liked learning about professional skills in the course. During their studies, 63 percent could apply the acquired professional skills often or very often. In their private life, 41 percent could apply the acquired professional skills often or very often. However, 51 percent found it useful for their private life. In their professional life, 75 percent could apply the acquired skills often or very often. 78 percent found it useful for their professional life.

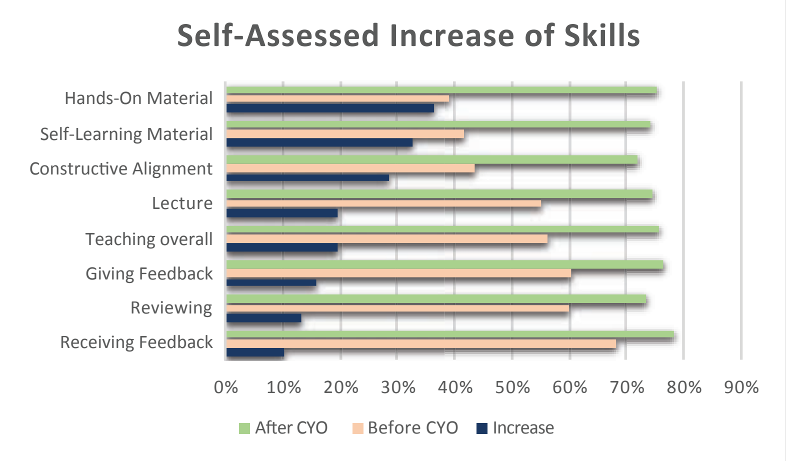

Figure 5. Increase in skills from most to least significant (59 participants).

Hard Skills: New Technologies Early

With the creative techniques at the beginning of CYO, the students are stimulated to select topics they consider relevant and interesting to include in the iLab. Through the umbrella topic selection and our feedback, we can guide this process.

All students participate in the lectures and therefore see each topic in the initial pitch, the first lecture, the review presentation (PreLab, Lab), and the second lecture. In addition, they all have full access to all creations. This results in knowledge on all topics.

In the survey, the students report having 50 percent expertise in the non-reviewed other teams' topics after the CYO compared to 31 percent before, resulting in a 19 percent knowledge increase.

For the reviewed minilab, the students work more in detail on the technical content. Thus the learning is perceived as better, which the survey confirms with a reported knowledge increase of 30 percent from 39 percent expertise before to 69 percent expertise.

The best learning outcome is as expected for each team's own creation with a reported knowledge increase of 42 percent. Before the CYO the students report a knowledge level of 44 percent and afterward 86 percent expertise. Thus, learning by teaching is also well suited for individually teaching technical content.

On average, the students report 4/5 on how much they liked learning content with the CYO. This shows that not only were the learning goals reached, but also the students got very well motivated through the CYO concept.

Hard Results: Future Students

The CYO has resulted in more than 60 minlabs so far. They serve as a pool for the next student run. Future students benefit from this early inclusion of "hot" topics in the iLab curriculum. About 18 minilabs could be added to our regular catalog with minor improvements from our side.

To give an idea of possible minilab topics covered in the past, the pool of minilabs comprises "DANE/ TLS," "KRACK — Key Reinstallation Attack," "Time is Power — QUANTUMINSERT," "Hiding in plain sight: Covert channels," "Email Spoofing," "Network Scanning — Advanced Portscanning with nmap," "Hacking and Defense, The CYO resulted in more than 60 minlabs so far. They serve as a pool for the next student run. Future students benefit from this early inclusion of "hot" topics in the iLab curriculum. About 18 minilabs could be added to our regular catalog with minor improvements from our side.

Black hat or White hat? You decide!," "Mobility Support in IPv6: Mobile IP," "MQTT — An IoT Protocol," and "HTTP/2 — Make the Web Fast Again."

Conclusion

The presented Create Your Own Exercise (CYO) teaching methodology addresses two major challenges for (university) teaching today:

- Teaching students the professional skills that are demanded from industry
- Introducing relevant technological developments early in the curriculum, which is also demanded by industry

In addition, it proves to be a good methodology for actually teaching technical content.

We motivated our research with recent results from several other groups. After introducing the setting, we detailed the CYO methodology and assessed its effect on student education. The results show that the presented methodology is very promising. It brings excellent results regarding the professional skills and the teaching of technical content, and it results in early curriculum integration of new technologies.

Last but not least, CYO is very well received by the students, who enjoy participating and recommend the course.

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Biography

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