LESSONS LEARNED FROM TEACHING AND TUTORING **DESIGN THINKING FOR ELECTRICAL ENGINEERING STUDENTS**

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ABSTRACT
To deal with societal challenges, future engineers need new skills and competences. Design thinking is one such skill. The project Future Technology Studies (Dahle Øien, 2021) aimed to develop the study programs in technology at Norwegian University of Science and Technology (NTNU) according to future technological development, societal challenges, and industry needs. One of the findings from FTS was that technology students should learn Design Thinking. In this work, we study an implementation of design thinking in an electronic engineering study program. Specifically, we use three perspectives, students, learning assistants, and teachers, to study how they experience the introduction of a cross-disciplinary topic in a domain-specific project course. The target group were electrical engineering students (N=117) who did a user-centered electronic system in a project-based introductory course in electronic systems design. Drawing on findings from a web-based questionnaire from students (N=67) and interviews with course staff members and tutors (N=13) our findings show (1) that more work is needed to improve the course description, activities, syllabus, and student evaluation and (2) the importance of making the purpose and goal of including design thinking in the course clear for the students.

KEYWORDS
Cross-disciplinary teaching, future technology studies, design thinking, electrical engineering, design, CDIO, standards 1,3,5,7,9,11

INTRODUCTION
Today, technology is intertwined with almost all areas of our lives, affecting people's daily lives both in seen and unseen ways, and continuously enters and changes new domains of society. Society and society's challenges has grown increasingly complex as the rate of technological development has increased. Solutions to these challenges require more than a technical understanding, but also an understanding of the societal and environmental context of the problem. Thus, for the modern engineer, technical competence is required, but not sufficient to apply their knowledge to the benefit of both people and environment. To be able to educate the modern engineer we need to view the process of engineering as more than the simple application of science. Figueiredo (2008) suggests that there are four dimensions to an engineer: the engineer as a scientist (basic science), sociologist (social science), designer (design) and a doer (practical implementation). Engineering needs to be seen as a process where knowledge from these dimensions is used based on the specific context of the problem

the engineer is working on. Traditionally, engineering education has had a strong focus on the understanding of basic sciences, with practical implementation of basic science being introduced towards the end of a degree. However, there is an emerging understanding of the need for the other two dimensions in engineering education. The needs of the modern engineer and modern engineering education has recently been looked into by the project Future Technology Studies at NTNU (FTS) (Dahle Øien, 2022) and highlight the need for strengthening the engineering students' competences within the design and social science dimensions above. FTS ran between 2019 and 2021 at NTNU with goal to «facilitate NTNU's study portfolio in technology to be as closely aligned as possible with technological development, societal challenges and the needs of business and working life in the period from 2025 onwards» (Bodsberg, 2020). In addition, the reports Engineering change – The future of engineering education in Australia (P. L. Lee, 2021) and Navigating the Landscape of Higher Engineering Education from the Technical University, Delft (Kamp, 2020), both highlight that future engineers need competences outside application of science.

These reports predict that the futures for engineering work are characterized by more complexity, more multidisciplinary, greater accountability, more focus on sustainability, and being performed on a global arena. Future expectations of professional engineers are that they have skills and competences that excel the past engineering work. Some of these skills are human focused impacts, design thinking, problem finding/framing/solving, multi-disciplinary collaboration and communication, stakeholder interaction, creativity, and imagination (Crosthwaite, 2021). All of these are important elements of working on projects with *design thinking* (DT) as a framework.

Design thinking is a framework that gives students and educators structure and tools to address problems with unknown solutions and wicked problems. The framework is a human-centered iterative problem-solving approach for developing innovative technologies, products, and services. The approach involves (a) identifying a problem and map and understand user needs, (b) developing concepts and proposals for solutions through creative development methods, sketches, and prototypes, (c) systematically testing the solutions on end users, and (d) improving the solution through iterations of the process. The framework, which exist in numerous variants and modifications and is usually explained through the five phases described in Figure 1.

Figure 1: Phases and example methods of the design thinking framework

The topic of teaching problem solving and more specifically design thinking to engineering students has been researched extensively from several angles for decades, including – but not limited to, researchers in the fields of design education and CDIO.

Previous research have – among other things, looked at comparing junior and senior engineering students approaches to solving open ended problems (C. J. Atman et al., 1999) (C. Atman et al., 2005), comparing engineering students and expert design practitioners (C. Atman et al., 2007) and how students' design processes differ and develop through the course of an engineering program (Cardella et al., 2008). Other researchers have looked at course design and didactic aspects of teaching design to this group of students (Lilliesköld & Östlund, 2008) including strategies for learning (Vattam & Kolodner, 2008). Similarly, observations on how to how the topic of design thinking may find its way into a CDIO context can be found in the works of Fai (2011), Ping (2011), Lee et al. (2014) and many others.

While there have been a number of articles exploring the effects of teaching and tutoring on the design thinking competence among engineering students, here we report on the experiences from introducing design thinking in an already established project course, focusing on the implementation itself from three perspectives – the student, the student learning assistant, and the teacher.

In this work, we have introduced design thinking in a first-year project course given to electrical engineering students through a collaboration between departments of design and electrical systems at NTNU. While similar studies have had a focus on the learning outcome, behaviors or competencies, the aim of our study has been getting more insight into the process of integration. Firstly, to gather data from student tutors and teaching staff about their experiences related to teaching and tutoring a cross-disciplinary topic to a new group of students. Secondly, we wanted student opinions about learning and using a cross-disciplinary topic to solve a problem in their own domain.

Design Thinking for technologists

As a case to study how DT can be integrated in engineering education, we used a five-year master's degree program in Electronics Systems Design and Innovation (MTELSYS) at NTNU. At this program students learn how to design and develop electronic equipment and systems. The study program has a foundation of mathematics, physics, and programming in combination with digital technology. The study program starts with a basic course in Electronic System Design (ESD) for its approximately 120 students (Department of Electronic Systems, NTNU, 2023a). The course is organized around the first phase of a larger innovation project in collaboration with an external company or organization with a real-world problem (Department of Electronic Systems, NTNU, 2023b). The students work in groups to make a prototype, using microcontrollers, sensors, and actuators, that can contribute to a solution to the collaborator's problem, with the goal of learning how to design simple electronic systems. ESD is divided into two parts: the introductory weeks and the innovation project. The introductory weeks aim at giving the students the basic competency needed to be able to contribute to the innovation project in the second part. The introductory weeks have until now focused on giving students practical skills within electronics through several short microcontroller-based exercises.

To counterbalance the heavy technology focus in the course and to make the project results more useful for its stakeholders, the course coordinator (co-author Bolstad) reached out to an employee at Department of Design (co-author Alsos), who was teaching a comparable course for industrial design students (Alsos, 2015), to see if they could exchange ideas. As a result, in 2019 the two course coordinators started an undercover learning assistant (LA) exchange program where LAs employed at the industrial design program were lend out to tutor students at the electronic system design program – and vice versa. Coming from different Faculties (Architecture and Design / Information Technology and Electrical Engineering) the undercover label was given to avoid any bureaucratic, organizational, and economical obstacles. In 2021 Design Thinking was introduced formally as a part of the curriculum.

The motivation for introducing DT in the ESD course was four-fold. First, it was observed by the teachers involved in the course that while the students created well-crafted electronic systems, they did not necessarily create systems in line with the needs of the external collaborator. Second, the competences gained through learning DT would make the course more constructively aligned with the course's intended learning outcome of giving the students a "beginning identification with the role of technological problem solver and innovator" (Course - Electronic System Design, Basic Course - TTT4255 - NTNU, n.d.). Third, it has previously been found that the students have a limited view of design and considers design as mainly being related to aesthetics and other exterior aspects of the prototype and reveals a belief that innovation is mainly a technological challenge thereby limiting the cognitive room available to the students when asked to work as engineer in the innovation project (Bolstad et al., 2021). Lastly, the NTNU project Technology Studies of the Future explicitly mentioned Design Thinking as competence that technology students should learn (Dahle Øien, 2021b, p. 13).

The DT module was called Design thinking for Technologists and was implemented as a 2,5 ECTS micro module. It was not a standardized, stand-alone course of the usual 7,5 ECTS, but was dependent on running in parallel within an existing project-based course, a kind of host which it could live in symbiosis with. The module took advantage of a pre-existing and not too specific curriculum and introduced new topics into the syllabus, but without changing the overall structure of the course nor the type of assessments. The learning outcomes and curriculum of the module was simplified compared to other design thinking courses, and carefully adapted to the target group. The number of methods they learned within each stage of the design thinking process was reduced to a minimum. In addition to teach and tutor DT framework and methods to the technology students, the aims were also to test out the integration of a DT micro module into an existing project-based course, to explore new financial distribution keys and performance allocation, and to encourage interdisciplinary collaboration and coordination between different faculties.

In conjunction with the introduction of DT, as described in this work, the introduction weeks were reworked. Instead of short exercises in week two and three, the students use DT in short one-week projects. There, they were asked to empathize with end users, define the problem, and ideate, prototype, and test solutions based on microcontrollers while having access to instructions on how to create useful parts of the prototype system, for example how to communicate wirelessly between microcontrollers. For more details on the structure of the course see (Lundheim et al., 2016). In the rest of this paper, we summarize the assessment of the Design Thinking pilot that ran in parallel with the ESD course during the fall semester of 2021.

METHODS

The aim of this study was (1) to assess whether the design thinking module gave the candidates competences in design thinking that enables them to develop user-friendly technology, and (2) to find out if the concept of micro modules integrated into an existing course. We used a two-pronged approach to investigate the student and staff experiences with regards to testing out the design thinking module. Staff, student tutors, and student representatives were interviewed with the goal of getting an in-depth understanding of the subject matter. We also conducted a survey with students at the end of the course and as part of the general course assessment. The purpose was to shed light on the design thinking competency development by students.

All the students in the course (N=117) were asked to take part in a course quality survey at the end of the course. Of these, 57 % participated in the survey (N=67). They answered a subset of 31 questions (from a total of 96 questions) that were directly or indirectly relevant for their experience with learning about DT. The students were asked on a five-point scale how much they agreed on various dimensions about the course (such as prior knowledge, satisfaction, relevance for study program, difficulty level, workload, information, teaching, supervision, learning environment, resources, project work, assessment, etc.). Some of the questions were directly relevant for the DT module (such as the prior information about DT, teaching, and tutoring in DT, the learning environment in DT, use of DT in the projects, the assessment of DT, and any other comments regarding the teaching, tutoring, and assessment on the topic of DT). In this work we present the results from a subset of these questions, specifically the perceived quality of the teaching and resources, the reported development of understanding electronic systems and DT, and in which arenas of the course this understanding has been developed. The subset was chosen based on the research questions and the thematic analysis of the interviews. To check for statistical significance the Wilcoxon Signed-Rank test is used, which is a non-parametric version of the paired t-test, with a significance level of 0.05.

Using guidelines and an approval from the Norwegian Centre for Research Data (NSD), we interviewed two reference group members (N=2) out of four total reference group members, eight learning assistants (LAs) (N=8) out of ten total LAs, and three teachers (N=3) out of four total teachers. They participated in a qualitative, semi-structured, and open interview about their general experiences in being taught/teaching and tutoring design thinking and their suggested improvements. In total, 13 persons within these groups, in including the co-authors of this article, were interviewed by the first author of this article. To avoid any bias, the coauthors were not involved in the development of the interview protocol, data collection, transcription of data, nor thematic analysis. The interviewees came both from the Department of Electronic Engineering (N=10) and from Department of Design (N=3).

After conducting the interviews, we transcribed the recordings into anonymized text for further processing using NVivo using *thematic analysis* (Braun & Clarke, 2006). We carefully examined the interview transcriptions to identify patterns and common themes using a six-step process: familiarization, coding, generating themes, reviewing themes, defining, and naming themes, and writing up. The quotes used here has been translated from English to Norwegian by the authors.

Limitations

There are several limitations with the approach used here. In the survey, we use self-reported data on learning, which might not reveal the true learning as they are novices within the field. With regards to the interviews, using reference group members as interviewees can be beneficial as they should have an overview of the general views of the student group. However, as they have self-selected to be a part of the reference group, they might be especially motivated or interested in the subject.

RESULTS

When asking the students about the quality of the DT module as compared to the rest of the course, they report a lower quality for the DT module across all measured areas as seen in figure 2A, with the differences being statistically significant. The largest differences are seen with regards to the reported quality of the location and resources. As the location was constant throughout the course, the difference must be a result of the quality of the resources available. Larger differences are also found for the quality of the use of DT in the introductory weeks, in the innovation project, and in the assessment, compared to the other elements of these activities.

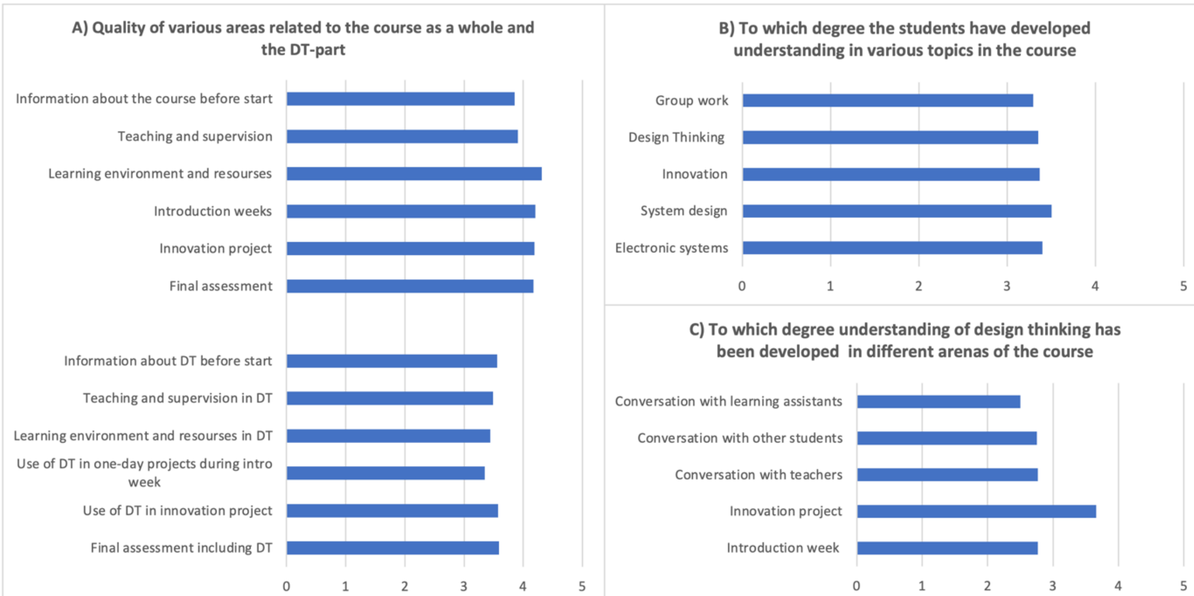

Figure 2: (A) The reported quality of various aspects of the course in general and the DT module in particular. (B) The reported development of understanding for central topics in the course. (C) The reported development of understanding for central topics in the course

Despite the reported differences in quality, when asked to report their development of understanding of topics central to the course such as electronic systems, systems thinking, innovation, groupwork and DT, the differences are small (figure 2B). The difference between the developed understanding of electronic systems, the central theme of the course and associated program, and the developed understanding of DT is not statistically significant. Examining the understanding of DT further (figure 2C), we find that the students report that their understanding developed the most through working on the innovation project, more than through the activities in the introductory weeks or through conversations with teachers, students, or LAs.

We then went from looking at the DT learning experiences among the students in the survey, to looking at the individual teaching or tutoring experiences among the teaching staff (TS) and learning assistants (LAs) in the interviews. Our key questions centered around what the participants felt was positive with the teaching/tutoring task they had been through, and where they felt the DT-module had room for improvements. From a general perspective, we noted that very few of the interviewees had negative experiences to report, and that there were a wide variety of constructive suggestions on how to improve the module.

Starting with the former, LA1 from the department of design stated that first year students, unfamiliar with design thinking (DT), will more easily enter a state where they do not consider the end goal of the project, ending with poorly considered features in the solution they are designing and building. Introducing DT and using LAs with DT background gives the students a reason to think about the end-user value their project creates:

So, I think it is only useful for them to be confronted with the fact that someone explicitly asks you those questions, such as "why have you chosen to do this? And […] what value does it actually create? I think at least as first graders – it's very easy for them to fall into that "here's a really cool thing to do - we have to do it here" mentality. And then they just do it, and then they build on it with features, and then it's ... it just becomes a mess

Several LAs recruited from the Department of Electronic Systems (IES) gave us similar feedback about the positive aspects of the course, highlighting the DT activities in the introductory weeks as important for the success of the DT module:

I think it was good that it was planned and that there were introductory weeks at the start, […] then they have a little understanding of what the level of ambition is placed and what they can achieve.

Furthermore, LAs also note the importance of focusing on user-centered insights and being able to take stakeholders in to account for these students' futures as engineers:

[…] now it has also come to the point where you have to think about the consumer... it gives some insight into what problems actually come up... here, there is a lot more we can actually think about, really.

Through using LAs from the Department of Design (ID), in addition to the learning assistants from IES, the students receive guidance and support, helping the students start to develop the mental pathways necessary for DT. The first one of the two reference group members in the class we interviewed, focused on the inspiring learning assistants from ID as one of the key positive aspects of the module:

… they showed off their projects and we have received reports from design students to see how they design it and think.

One of the members of the teaching staff (TS1) at the Department of Electronic Systems (IES) we interviewed, also call attention to how DT incentivizes students to reflect on their goals through the *empathy* phase and its focus on the end-user. Furthermore, the staff member echo the statements by the LAs, highlighting the introductory weeks as important for the DT module, where the one-day projects gives the students an understanding of the process and the usefulness of DT:

…The fact that we include is this empathize phase that comes at the very beginning where you justify… I think that has worked very well, that the students have to justify the need for the solution before they start thinking about ideas and before they start implementing the ideas or the concept/solutions. […] I feel that the students have gained a lot from that…
[…] and when we facilitated those one-day projects in the intro weeks, where they had to go through... within one day they had to go through the whole loop, also test by making a cardboard prototype in just one day... And these were students who were only... they haven't had any technical training before this, so they really can't do much - and I felt that worked very well, and I think that in a way they got to know the power of the design thinking module and -process. I definitely feel that we have to take that forward.

TS1 also commented on the potential improvements of the design thinking module, including maintaining the pressure on the students to connect their effort to empathize with the end-user at the start, with the project´s final result:

[…] they must show very clearly that the prototype and the solution they end up with, it is connected to the work they have done in connection with "empathize" and the idea generation phase and not least the testing phase and that it (the work) is connected in several iterations then. The way the students are now presenting it, there are fairly linear processes up to the prototype, and I think there is clearly potential for improvement there. By trying to permeate that design thinking process further into the subject then - towards the deadline as well, right up to the deadline.

TS1 was not the only one with suggestions for improvements. The first LA we interviewed suggested that the interface/transition between the course and the design thinking module needs work, but had no specific suggestions:

...I simply think that finding a slightly softer transition between design thinking and .... the technical aspects of the subject. I think that would have helped a lot.

The second reference group member also gave us a suggested improvement when noting that the placement of the lecture about design thinking could have a higher impact if it was move to an earlier place in the course:

[…] perhaps move that lecture a little earlier or do it in a different way, then perhaps even more would have entered that basic knowledge and it would have been easier to use them.

One of the LAs that reported to be an experienced 4th year student, highlighted the importance of being physical close and accessible to the students:

[…] the most important thing for the subject ... and for you to use us learning assistants because it is very nice for them, is that they see us... and that we are very accessible. Because of that, we noticed a difference this year as well. That the groups that sat inside the [space reserved for the course], they used their learning assistants much more than the groups I had that sat outside...

Learning assistant number five from MTELSYS, also commented that the course could improve by collecting and recycling materials for the prototypes, and improve by making it possible to pull them apart again, for yet another re-use of the materials used:

And one more thing. You must remember improvement. They have taken... put now, the now to be environmentally friendly when we see that there is a new project every year. Then it was easier to be able to use fins or one thing or another, or if the school could bring in things that can be reused then, because it becomes more like that, everything is done there, and then it is glued, and then things become torn apart and unfortunately cannot be used again. Because it should also be in the future.

Reflections-On-Action

As a form of reflection-on-action (Schön, 1983), the second and third author of article reflect as follows on their own actions of creating and testing the design thinking micro module:

Our purpose of the module was to give technology students competence in design thinking so that they could learn to make technology with value for individuals, organizations, and society, not only for the sake of technology. Based on our impression, we think that we succeeded in introducing design thinking to the engineering students and changing the way they think about the importance of end users. However, varying degrees of application of DT by the groups in the innovation project was observed, resulting in prototypes with a diverging alignment between function and real user needs.

One of the main challenges for us was to find a way to fit the design thinking syllabus into the MTELSYS study program. Study programs are usually completely full, and to wedge in yet another course is impossible without taking another course out. In addition, it would not make sense to arrange a design thinking course without a project to apply the design thinking framework. This project should not be any random project but should be aligned with the learning outcomes of the study program. Therefore, our solution was to create a micro module that could float on top of an existing project-based course.

Because of the size of the micro module the students could only learn a limited number of methods from the design thinking framework. We had to carefully select a few methods in each phase.

Flexibility from all involved parties was essential to allow the close course integration of the DT module. The prior collaboration with the LA exchange and the personal relation and mutual respect we developed was important to make this collaboration possible. This initiative started as an undercover operation over several years but was later normalized through an official pilot.

DISCUSSION AND CONCLUSION

Building on the survey, interviews, and reflection on action, we will in this section discuss the effect, design, and transferability of this module. Despite the students reporting that they experience the quality of the DT aspects of the course as lower than the rest of the course, they still report the same degree of development of understanding of DT as of electronic systems. The lower reported quality might arise from a frustration from engagement in DT concepts foreign for the students. In the interviews, the Las and staff highlight how the integration of DT forces the students to make new mental pathways and make considerations that might be counter to their instincts as first-year engineering students, matching the intended goals of the module. This frustration is also found when business students are exposed to DT project work (Glen et al., 2015) . The ability to manage frustration and uncertainty and integrate new concepts are important skills that an engineering program needs to develop in its students in order to prepare them for a world with wicked engineering problems (Dahle Øien, 2022). However, too much frustration will lead to a disengagement with the DT in the students, which was observed in some groups, especially for students with low tolerances for uncertainty. Integrating DT in a first-year course needs to focus on simple activities and manageable goals to achieve a degree of frustration in the students that encourage the engagement and reflection that create new mental pathways. The activities in the module described in this work seems to be close to finding this balance as the reported development of understanding is similar to other central elements of the course.

We observe that the most important arenas for the development of understanding of DT are the introductory weeks, as reported by LAs and staff through the interviews, and the innovation project, as reported by the students in the survey. That the students report the innovation project as the central learning arena is natural as the majority of the semester is spent working on the innovation project. However, from the interviews and own experiences we believe that the learning from innovation would be severely limited without the introductory weeks. They provide the necessary mental scaffolding to allow the application of DT on the real-world wicked problem given in the innovation project. However, there are signs that this scaffolding needs further improvements, as there are signs that the students did not work through iterations as intended, but rather linearly.

To increase the understanding of DT as a result of the module, there needs to be an even closer integration of the DT and technical aspects of the course, with more assistance from LAs and supporting activities. In this regard, using a course and a project relevant for the study program is essential. Using skills developed in a general context can be cognitively difficult to apply intuitively to other specific contexts (Perkins & Salomon, 1989). Therefore, if we want to give the students the ability to utilize DT on problems they will face as engineers, teaching them within a relevant context is important.

A closer look at the constructive alignment (Biggs, 1996) in the course and to what degree the assessment is aligned with the learning activities and tutoring may also be relevant to an improved micromodule in this specific case.

An important goal for the development of this module is the possibility of giving similar modules to other engineering programs. A central challenge for the transferability of the module is the origin of the module in a personal interactions and connections. The module has been developed and tailored for the course over several years and through continual collaboration. One could argue that it will be too difficult or too time consuming to establish such personal connection for every new integration of a DT module. However, the transformation of education, that for example the host institution of this study is facing (Dahle Øien, 2022), requires more collaboration across courses and across disciplinary boundaries. Placing a larger emphasis on creating arenas and situations where these connections can be established might be a requisite for the success of such transformation efforts.

A last challenge for the transferability is the organizational obstacles. IES and ID are located at different faculties. The incentives for co-production of courses across faculty barriers are low, as faculties are independent organizations with their own budget, employees, and courses. Exploring how a culture for integrating, teaching, tutoring, and evaluating design thinking may spread to a larger NTNU audience of programs, courses and staff, should be the goal of further studies.

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