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The competence studio as an agile teaching format - Biomechanics project work up to the prototype

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Abstract

Um den Campus im Zeitalter von digitalen und hybriden Lehrveranstaltungen wieder attraktiv zu machen, wird ein agiles Lehrformat vorgestellt, das die kooperative Problembewältigung durch projektbasiertes Lernen und agiles Projektmanagement ins Zentrum stellt. Hierzu werden zunächst allgemein die Elemente agilen Projektmanagements vorgestellt und anschließend die Übertragung auf den Lehrkontext erläutert. Zur weiteren Verdeutlichung des Ablaufs und des Zusammenspiels der Gruppenmitglieder wird am konkreten Beispiel des Moduls *Kompetenzatelier: Biomechanik agil mit Scrum* die Durchführung beschrieben und das schrittweise Erstellen eines Demonstrators durch die Studierenden gezeigt. Abschließend wird die Evaluation des Kompetenzateliers zur Identifizierung von allgemeinen Stärken und Schwächen genutzt. Dabei wird besonders auf die agile Reaktion der Studierenden auf geplante und ungeplante „Störelemente“ eingegangen. Das Kompetenzatelier bietet für Lehrende kleiner Studiengänge und Gruppen eine Anregung zur innovativen und kreativen Auseinandersetzung mit einem agilen Projektmanagement und fördert die Selbstmotivation zum Lernen durch eine unmittelbare praktische Anwendung.

To make the campus attractive again in the time of digital and hybrid teaching, an agile teaching format is presented that focuses on cooperative problem solving through project-based learning and agile project management. Therefore, the elements of agile project management are first presented in general and then transferred to the teaching context. For further clarification of the process and to show the cooperation of the group members, the actual example of the module Competence Atelier: Biomechanics agile with Scrum, is described including the step-by-step creation of a demonstrator by the students. Finally, the evaluation of the competence atelier is used to identify general strengths and weaknesses. In particular, the agile reaction of the students to planned and unplanned "disruptive elements" will be addressed. The competence atelier offers teachers of small courses and groups a stimulus for innovative and creative engagement with agile project management and supports self-motivated learning through immediate practical application.

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1. Introduction

The establishment of digital and hybrid courses is accompanied by the question of the necessity and value of face-to-face teaching. The experience of the Corona pandemic clearly showed that face-to-face teaching not only has decisive advantages for students' sense of belonging, but that practical teaching formats are also highly valued in the university context. The question arises as to how this added value of face-to-face teaching can be increased and made clear to students.

The teaching staff of the Chair of Biomaterials at Dresden University of Technology took on this task in order not to simply follow the path back to long-established teaching formats after remote teaching during the Corona pandemic. The focus was therefore primarily on the continuation of the newly established digital techniques and feedback formats, the use of elaborately created videos of the digital and hybrid semesters, and the integration of these elements into a new teaching concept.

During the Corona semesters, many digital and hybrid lecture and seminar formats as well as practical courses with digital communication tools and Lab@Home approaches were implemented in the teaching activities of the Chair of Biomaterials. These (experimental) lectures, seminars and practical courses took place as synchronous and asynchronous online as well as hybrid events [1,2]. The importance of practical training elements and the high significance of students learning together - under the guidance of the teachers - became particularly apparent in the course of this challenging time.

Three courses were redesigned to emphasize the values and importance of face-to-face teaching for students. The focus of these so-called "Competence Atelier" is the joint development of a prototype or a demonstrator in the form of a product to solve a real-life or work-related problem. The respective problem is oriented to the subject matter, which ranges from *biomechanics*, *quality assurance and statistics* to *sustainable materials*. The aim is to activate the full spectrum of methodological, subject matter, personal and social skills in the students.

The development of the *Competence Atelier: Biomechanics Agile with Scrum* for students in the 8th semester of the Materials Science study program was primarily based on the experience with the workshop *Biomechanics in Everyday Life* (2nd semester). This was further developed into a synchronous digital practical course with asynchronous activity phases during the time of the Corona pandemic [3]. Here, the focus was on promoting self-competence and methodological competence.

In the following chapter, agile project management, as established e.g. in the field of software development with the Scrum framework, is first explained. Subsequently, the transfer to a university teaching format is described. Since the process, the personal roles, and the teaching elements (artifacts) deviate from classic teaching formats such as lecture, seminar and lab course, the term competence atelier is used in the following.

Finally, there is a chapter on the specific implementation of the competence atelier using the example: Biomechanics agile with Scrum. The evaluation and student feedback on this example serve to assess the new teaching format.

2. Agile project management

Agile time and project management based on Scrum according to Ken Schwaber and Jeff Sutherland follows a strict but universal set of rules, which is not limited to the originally addressed software development [4]. Agile methods are characterized by an iterative development process. Instead of working through an extensive catalog of tasks in order to develop a final product, small iteration stages are implemented in demonstrators in order to obtain feedback from team members and clients at an early stage. This allows a quick and flexible - i.e. agile - response to changing requirements.

The use of agile project management methods in the context of a university course serves to convey specialized content in a practice-oriented manner using the widespread working methods of teams and work groups in many companies [5]. There are three central aspects, the roles, the events and the artifacts. Their correspondences in the teaching context are assigned in chapter 3.

In general, the organizational framework of Scrum defines the roles of a Product Owner, a Scrum Master and the Developers for a team of max. 10 people. A functional explanation is given in chapter 3, which describes the transfer to a lecturing context. The chronological sequence of a project according to Scrum is divided into so-called sprints, which in turn are subdivided into a sprint planning session, daily meetings (Daily Scrum), the actual work phase, a sprint review and a sprint retrospective. The interaction of the Scrum elements is schematically summarized in Fig. 1.

Individual increments or prototypes of a finished product are developed during the sprints, increasing the complexity of the product over time. The so-called artifacts are used for group organization and documentation. These include the product backlog as a prioritized list of increments to be worked on in order to generate a product with the most important requirements as quickly as possible.

The Product Backlog is always oriented towards the goal of the entire project, i.e. the wishes and requirements of the customers or finally the users. In the sense of agile project execution, this backlog is always refined and effort as well as risk estimates are made for the prioritization of the individual increments.

For each Sprint there is a Sprint Backlog, also a prioritized list of tasks that are processed until the respective "*Definition of Done*" is reached. During the Sprint, the Developers work through the individual work steps (Items).

The Product Increment already mentioned represents a delimited (partial) competence or individual functionality of the final product. This must be generated by the team within each Sprint and its functionality should be testable. Then the "*Definition of Done*" is fulfilled.

This initially abstract description of project execution with Scrum is transferred to the specific context of a university course in the following and the generalized teaching format "Competence Atelier" is derived from it.

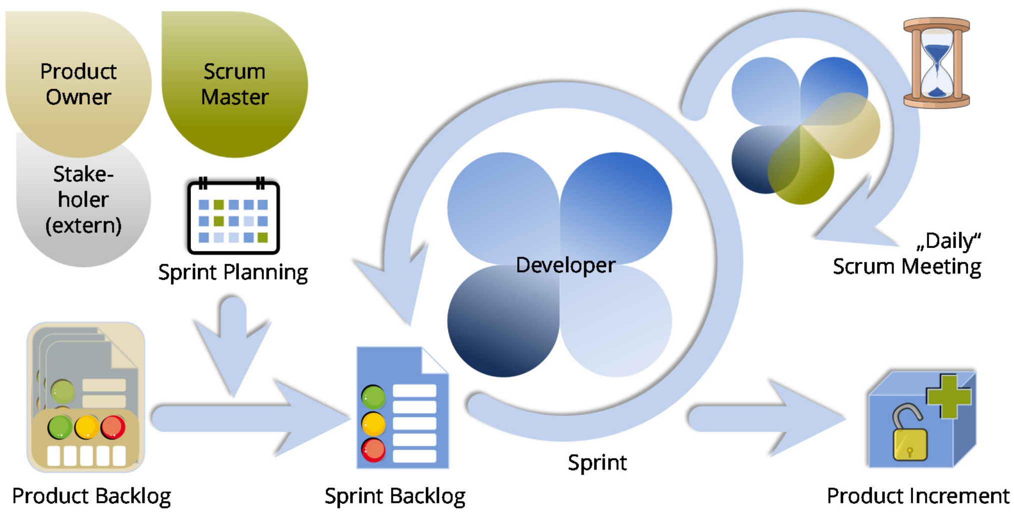

Fig. 1: Schematic representation of the project management work cycle according to Scrum

3. Agile with Scrum in University Teaching - The Competence Atelier

In the new course format of the Competence Ateliers, the focus is on cooperative problem solving and project processing. In order to enable students to work together as efficiently as possible, they are first introduced to agile project management (based on Scrum [4]Fig. 1). By directly applying the agile method, they internalize the roles (Scrum Master, Product Owner, Developer team), events and artifacts through their own experience.

The general Scrum rules were adapted to the constraints of university teaching (weekly rhythm, double lessons, group sizes, role assignment, etc.) (Tab. 1). With the planning described here, the Competence Atelier is feasible for courses with 4 semester hours per week of 45 min each (2 double lectures) and up to 12 students in one room. For up to 24 students, the Competence Atelier can be implemented with two rooms or one larger room. Since the lecturer is in a deputy function of the Scrum Master, she or he cannot participate in the "Daily" Scrums of two groups. Therefore, an offset of approx. 20 min (especially in the first Sprint) is advisable in this case.

Tab. 1: Semester schedule for a course with 4 semester hours per week of 45 min each (2 double lectures) with color coding of the 3 sprints. In contrast to the Scrum framework, the "Daily" does not take place daily but weekly, at the beginning of each appointment as an hybrid or face-to-face event.

Week	Duration / min	Content of the Competence Atelier	Learning units
1	90	Thematic introduction (in the current example: biomechanics)	Digital short videos, exercises, quizzes as 10-30 min self-learning units, permanently available and individually retrievable via Videocampus Saxony or Opal.
	90	Introductory event on the project management method Scrum, (group formation)	
2	30	Assignment of roles (in the groups)	
	60	Meeting with stakeholders or development assignment, define requirements profile	
	30	Creation of the Product Backlog	
	30+30	Planning Sprint **1**, creation of Sprint Backlog; Sprint 1	
3	15+75	"Daily"; Sprint 1	
	90	Sprint 1, Backlog Refinement	
4	15+75	"Daily"; Sprint 1 Review	
	15+75	"Daily"; Sprint 1 Retrospective and submission as a 1st protocol (until next appointment).	
5	15+75	"Daily"; planning **Sprint 2**, creating Sprint Backlog.	
	90	Sprint 2	
6		*(lecture-free)*	
7	15+75	"Daily"; Sprint 2	
	90	Sprint 2, Backlog Refinement	
8	15+75	"Daily"; Sprint 2	
	90	Sprint 2, Backlog Refinement	
9		*(lecture-free)*	
10	15+75	"Daily"; Sprint 2 Review	
	45	Sprint 2 Retrospective and submission as a 2nd protocol (until next appointment).	
11-14	Σ = 720	**Sprint 3** (according to procedure VL 5-10) with submission of the 3rd protocol (until 1 week before the exam).	
Exam time		"Daily"; Release: Group Exams	

This results in the descriptions of roles and artifacts in the teaching context summarized in the following:

Stakeholders (module supervisor or lecturer, external experts as guests if necessary)

- Customers, clients, users or patients who "bring along" a task or problem,
- Deliver the task, which is reformulated by the Product Owner into the product goal,
- Are represented by the Product Owner during the sprints,
- Evaluate the increments or the final product after each Sprint,
- Implementation in the form of **a)** user stories as short descriptions of individual features of the desired product or **b)** stakeholder statements as several 1-2 page problem descriptions of various (fictitious)

organizations and persons or **c)** stakeholder interviews in the form of expert discussions for problem description and product idea generation.

Product Owner (1 student per group)

- Has a vision of the final product after exchange with stakeholders,
- Responsible for the final properties as well as economy,
- Continuously develops the Product Backlog, determines priorities, values and risks of the individual increments and items,
- Explains the requirements and product features to the developer team.

Scrum Master (1 student per group supported by 1 lecturer)

- Responsible for compliance with Scrum rules and timeboxes,
- Helps to manage the Product Backlog/ Sprint Backlog transparently,
- Provides techniques for group management and constructive collaboration,
- Moderates "Daily" Scrums, Sprint Review, Sprint Retrospective,
- Documents project progress in a collection of protocols (submitted after each Sprint as part of the evaluation),
- Lecturer is responsible for more general aspects (access to labs/rooms, technology, equipment) and supports in finding roles (especially during 1st sprint).

Developer (groups <10 students)

- There are no fixed roles in the team,
- Design a plan for the Sprint and maintain the Sprint Backlog,
- Estimate the effort of each backlog item, define the "Definition of Done" for each increment and item together with the Product Owner,
- Deliver product functionalities with priorities desired by the Product Owner,
- Work on items individually or in small teams during sprints (on-site or self-study).

Product increment

- Delimited (partial) competence or individual functionality of the product,
- Must be manageable by the developer team in one Sprint,
- Functionality testable (Definition of Done).

Item

- Individual work step - to be implemented by a developer or small team,
- Should not last longer than 90 min,
- Result together in a product increment or form the basis for it,
- Also includes learning the basics (provided instructional videos, practice materials, expert interviews, etc.).

Product

- Consists of increments developed/implemented during the Sprints,
- Each increment can represent a product (with limited functionality) as a demonstrator or prototype,
- Further increments add functionalities according to prioritization *(Backlog)*.

Product Backlog

- Prioritized list of increments to be worked on as a long-term project plan,
- Effort and risk assessment,
- Managed by the Product Owner and continuously refined and improved during Backlog Refinement (1-2 per sprint) - also in collaboration with developers,
- Part of the evaluation: Delivery as an approx. 10-page summary after each Sprint (Tab. 1).

Sprint Backlog

- Managed by the developers,
- Ordered list of necessary work steps of the current Sprint, including the *"Definition of Done",*
- Planning of processing a single item (should take < 90 min),
- Divided into "*ToDo*", "*In Progress*" and "*Done"* (the basis for *burn-down chart*).

Sprint

- 3-4 week interval (Tab. 1) for self-organized implementation of the *Backlog items*,
- At the beginning, the Sprint Backlog is developed during Sprint planning,
- At the end of each Sprint, a completed increment is delivered in the Sprint Review,
- Is completed by the Sprint Retrospective to improve team collaboration.

"Daily" Scrum (1x per week, max. 15 min)

- Prelude to each meeting, everyone must have their say - statements are not addressed (only to capture status),

- All persons answer 3 questions:

1) What happened since the last meeting?
2) What do I plan to do between now and the next meeting?
3) What is preventing me from achieving this goal?

4. Concept of the Competence Atelier using the example: *Biomechanics agile with Scrum*

According to the semester schedule (Tab. 1), an introduction of the students to the general topic of biomechanics and agile project management with Scrum took place in two hybrid lectures at first. The definitions of roles and artifacts were additionally repeated in further short teaching segments to give the students impulses for actions and tasks of individual group members. Owing to the participation of only 6 students, it was not necessary to form several groups. This was planned in advance from a group size of more than 11 students.

On the one hand, the biomechanics focus was ensured by already existing videos (24 videos of 20-80 min each, provided via Opal/Videocampus Sachsen [6,7]). This allowed the students to deal with the theoretical biomechanical basics at their own pace and according to their information needs for their project.

Stakeholder input was conveyed in the form of seven 1-2 page statements from various fictitious organizations and individuals (Figure 2).

The statements consisted, for example, of texts from a fictitious health insurance company that, as a client, would like to provide a product for patients to prevent aseptic loosening of hip endoprostheses. This input was complemented by a patient perspective on the rehabilitation process after implantation of an artificial hip joint. Furthermore, the perspectives of an implant manufacturer, a biomaterials researcher and a surgeon were provided as exemplary problem descriptions. The professor responsible for the module also sent a stakeholder statement to emphasize the importance of biomechanical principles for the project and the final demonstrator. From these statements, the students developed the product goal, which was phrased by the Product Owner as follows, "*Sensors wearable on the patient's body in everyday life to detect harmful hip positions to prevent implant loosening due to hip dislocation using direct feedback.*"

Based on this, the Product Backlog was derived and recorded as a task list for the iterative development of the demonstrators during the Sprints. As a written documentation platform for the Backlogs and the project/sprint progress, the students were provided with a Miro board via a free teaching license, which can be accessed independently of the operating system [8].

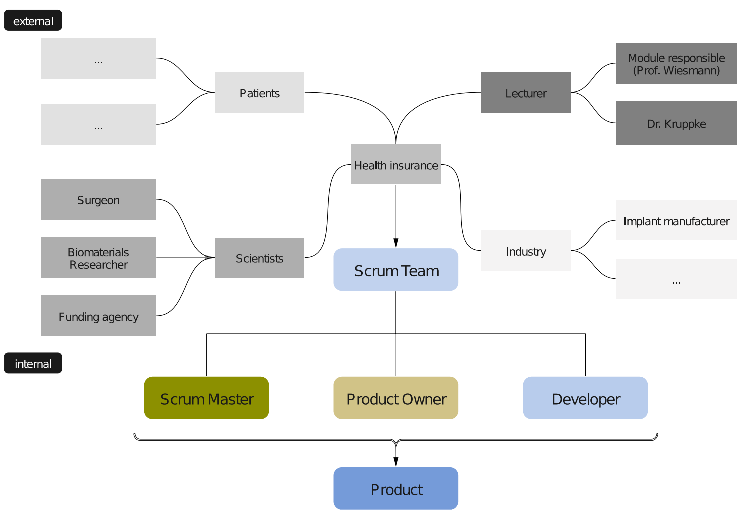

Fig. 2: Overview of exemplary stakeholders in "contact" with the Scrum team

Fig. 3 shows the schematic final state after one semester. The Miro-Board contains an overview of the students' appointments and notes in column 1. Column 2 shows the stakeholders and a template for the user stories, which was given at the beginning of the Competence Atelier. Furthermore, column 3 shows the product idea, the Product Backlog with prioritization and effort weighting, and the Definition of Done for individual increments. Column 4 contains the Sprint Backlog, a burn-down chart and a Kanban board for transparent assignment of the tasks to all team members, with the processing status marked as "To do", "In Progress" and "Done".

During the first Sprint, the students decided to record the biomechanics of the human motion using the motion sensors of cell phones (app phyphox ®[9,10]). Here, they focused on measuring the flexion angle between the thigh and the torso to identify harmful hip joint deflections in the case of artificial hip joints.

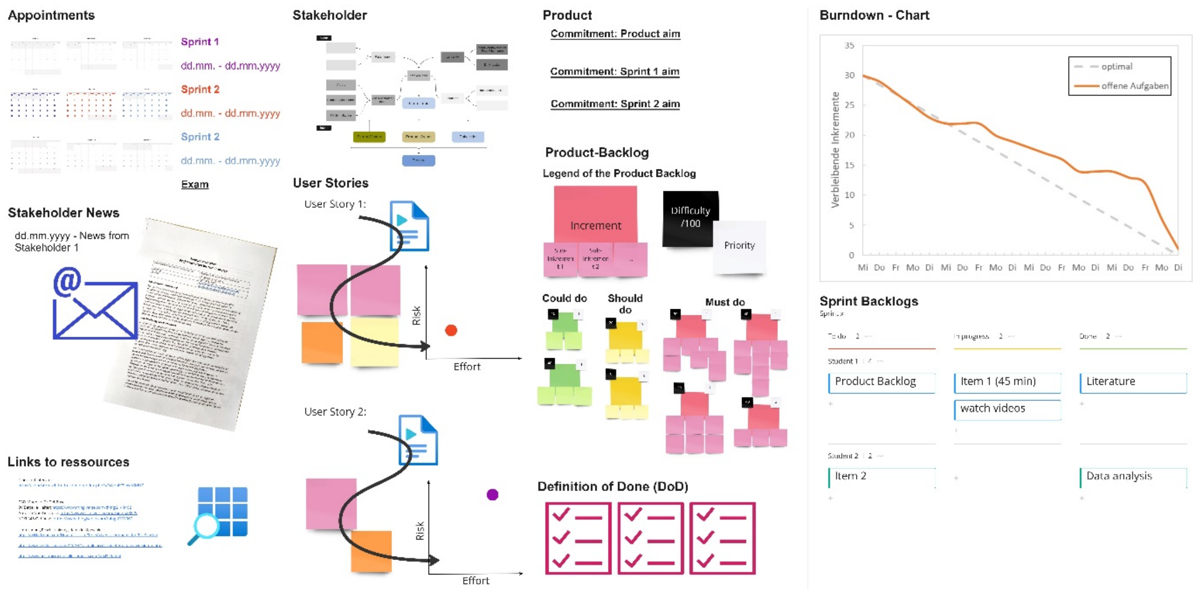

Fig. 3: The schematic Miro board of the Scrum team.

The increment (first demonstrator) was presented in the first Sprint Review, in which the angle measurement was demonstrated using two cell phones and the subsequent calculation of the damaging motion sequences. Subsequently, the requirement profile was sharpened for the 2nd Sprint.

The Scrum team showed its adaptability in the context of agile project processing when two new additive manufacturing devices (filament and resin-based 3D printer) including the materials for 3D printing were made available. In addition, students were able to use several Arduino microcontrollers with a variety of sensors and other electronic components.

Thus, the next Sprint Backlog included the implementation of an Arduino-based system with two sensors and production of the housings and a hip model to show the product's functionality using 3D printing (Fig. 4).

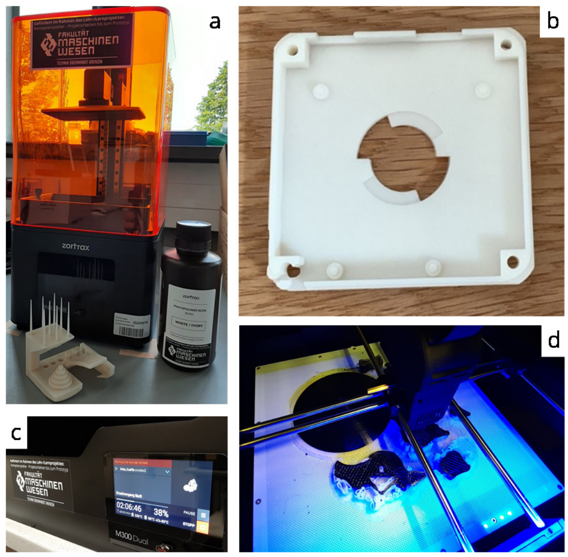

Fig. 4: UV LCD printer (a) and housing part for portable prototype (b), dual filament printer (c) and printing of a hip model as a presentation aid (d).

After each Sprint, the project progress was summarized in a protocol of max. 10 pages, which was created by the Scrum Master. The report summarizes the artifacts (Product Backlog and Sprint Backlog) and shows the Sprint progress as a burn-down chart. In addition, a retrospective view of the team's work is to be integrated into the protocol. Here, the measures (possibly necessary) developed during the sprint retrospective to improve the collaboration and performance of the developmer team are briefly discussed.

The final product *Hip.sense* was presented as a prototype (Fig. 5) and its functionality was proven during the final oral exam. It is a smart medical device which should help to reduce the number of aseptic loosenings of hip endoprostheses due to harmful movements after implantation.

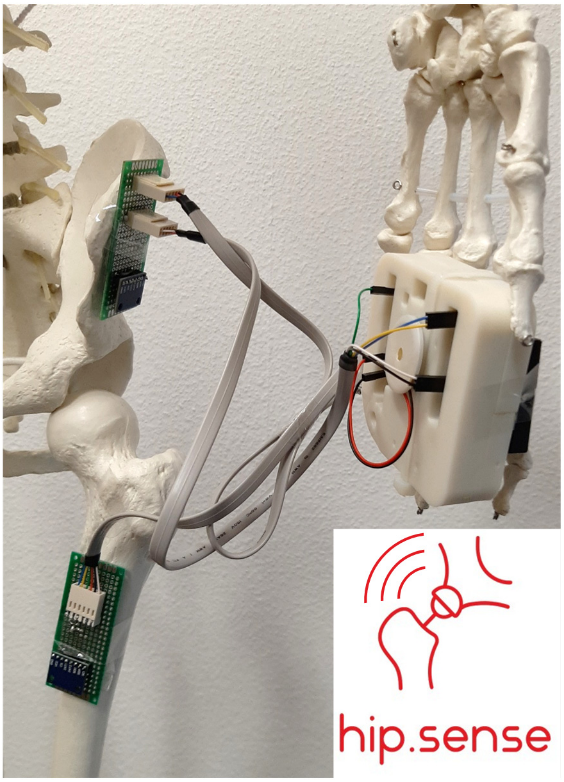

Fig. 5: Hip.sense prototype on a skeleton model with two accelerometers on thigh and hip and the Arduino controller with power supply and acoustic output.

Hip.sense detects the positions of the thigh in relation to the upper body and sounds an acoustic warning signal to avoid too much bending (when sitting down, tying shoes, etc.).

The prototype meets the following requirements:

- Affordable, readily available components,
- Expandable platform (other joints and movement pattern warnings),
- Portable power supply,
- Potential for miniaturization (e.g. fixing in special pockets on underwear),
- Customer-friendly demonstrator.

5. Evaluation and student feedback

The evaluation at the halfway point of the second Sprint revealed a predominantly positive assessment of the teaching concept, the introduction of agile project work, and the participating lecturers by the 6 students (Tab. 2).

Criticisms of the teaching format can be summarized as follows:

- Provide instructional videos as early as possible,
- Offer any available project resources (equipment, budget) early in the project,
- More stakeholder input and
- Perhaps communicate expectations more clearly at the beginning.

Among other things, these criticisms pick up on the additional stakeholder statements submitted after the 1st and 2nd sprints, which were explicitly intended as stimulating elements. Here, the advantage of agile project management became apparent, as the students had to react by adjusting their planning. As expected, these "disruptive elements" to kick off the agile restructuring led to criticism, but were integrated into the project in an exemplary manner.

The selected student comments suggest additional strengths and areas for improvement in the concept:

Student 1:

"*I find the creative concept of offering a project-based internship in addition to a compact, asynchronous course extremely good. The concept allows time flexibility and free focus by the students. All in all, this makes it one of the best and most innovative courses in the materials science program. Please continue to work on creative lecture concepts with integrated digital teaching for-*

mats to adapt university teaching to the realities of the current times! "

Student 2:

"Super lecture concept!"

Student 3:

"Pros:

- *Interesting concept with integration of compact asynchronous teaching content and practical group work (best teaching concept in my opinion)*
- *Time flexibility*
- *Access to 3D printers and microcontrollers*

Contra:

- *High effort in the practical part*
- *Introduction of the Scrum methodology and role reversal within the group should possibly still be reconsidered and adapted if necessary.*
- *Unclear how some user stories (material development, endoprostheses with looseness detection) will actually be implemented in practice"*

Student 4:

"More effort compared to other events. If the topic is good, it motivates to deal with it more deeply".

Tab. 2: Evaluation result (selection)

Statement	Completely true	Applies mostly	part/ part	applies little	Does not apply at all
Lecturer establish a link between theory and practice.	66.67 %	33.33 %	0 %	0 %	0 %
I find agile project management to be an enrichment in teaching.	50 %	33.33 %	16.67 %	0 %	0 %
I feel better prepared for the professional future with the methods of agile project management.	33.33 %	16.67 %	33.33 %	16.67 %	0 %
The practical elements are aligned with the course content.	16.67 %	83.33 %	0 %	0 %	0 %
The practical task leads to a deepening of the lecture contents and animates to deepen new topics.	33.33 %	50 %	16.67 %	0 %	0 %
I think the Competence Atelier is good.	33.33 %	66.67 %	0 %	0 %	0 %

6. "Lesson learned"

An essential component of the agile Competence Atelier is the step-by-step improvement of prototypes up to the finished product. After the individual work phases, the students should be able to present sprint prototypes and receive feedback on this from the course instructors (module leaders and teachers) and, if necessary, external stakeholders. This allows the students to subsequently revise their tasks and priorities and produce a new, improved prototype in the next Sprint.

With this concept it was possible to encourage students to work together and to get them newly excited about face-to-face teaching on campus. The following advantages and disadvantages were identified:

- Agile teaching format Competence Atelier allows adoption of proven digital elements (videos, Miro boards) and linking with face-to-face teaching,
- Project execution encourages students to work out specialist information independently (in the future, stronger incentives are planned through expert interviews),
- Scrum team works even if individual members fail - agile response by reassigning items,
- Meetings can be conducted hybrid (combined presence and online participation) and
- Incentives for development of technical content by all team members should be increased.

Teamwork and prototyping is only possible on campus and *hands-on* at the device. This is our contribution to demonstrate to both faculty and students the importance of face-to-face teaching.

7. Outlook

Thanks to the support of the teaching/learning project by the Faculty of Mechanical Sciences and Engineering at the TU Dresden, the methods of additive manufacturing and microcontroller programming could be made accessible to the students (almost) without restrictions. For demonstrator and prototype production, this will result in significantly expanded degrees of freedom in the future and the Competence Atelier is also excellently equipped for future runs. In future, the students will be able to try out very different and creative problem-solving approaches from the practice of applied biomechanics in each Sprint, but also from year to year.

The universal character was tested by the simultaneous introduction of this novel teaching format in the module *Competence Atelier: Quality Assurance and Statistics with Scrum* (also 8th semester). The flexible transferability is due to the project orientation of the Competence Ateliers and the focus on agile project and time management.

In the future, students will also be able to focus on new material developments in the field of biomaterials (degradable polymers) and the processing of sustainable materials (biodegradable composites, recycled polymers). Also, the microcontrollers on the Arduino platform can be flexibly used with a wide range of sensors. It is thus easy to determine characteristic values for biomechanical loads in everyday life directly as a basis for prototype production as part of a student project. In the specific case of biomechanics, the Competence Atelier as a teaching format can thus be adapted very flexibly to the circumstances of the department and the stakeholders and product ideas can be varied each year. Furthermore, the general design of the agile project execution in the Competence Atelier allows to adapt it to other modules and departments, to strengthen the importance of face-to-face teaching and independent project processing by students.

Acknowledgement

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