Redesigning the T7005T-Aerospace Materials course: a flipped learning approach

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Abstract

The design of the course *T7005T-Aerospace Materials* is analyzed according to the pedagogical principles of constructive alignment [1, 2]. It is found that a design issue exists, particularly in the section of the course devoted to damage in composite materials. This view is supported by the feedback gathered from students who attended the course in the previous academic year. Upon consideration of examples available in the literature, the flipped learning approach is regarded as a good fit to correct the identified design issue. Based on the analysis of the signature pedagogy [3] and of the threshold concepts [4] of Materials Science & Engineering, a new flipped-classroom design is proposed for the *Aerospace Materials* course.

> This report, by its very length, defends itself against the risk of being read.
>
> — Winston Churchill

Contents

1. Analysis of the constructive (mis)alignment of the T7005T-Aerospace Materials course

1.1. The T7005T-Aerospace Materials course

The course *T7005T - Aerospace Materials* is a 7.5 credits second-cycle level course in the subject of Polymer Engineering offered by the Department of Engineering Sciences and Mathematics. The course represents an elective option for first-year students (semester 2) of the Master Programme in Composite Materials, first-year students (semester 2) of the Master Programme in Materials Engineering - Track 2 Polymers and Composites and third- (semester 6) and fourth-year students (semester 8) of the 5-years Master Programme in Materials Science & Engineering (EEIGM) - no specialisation track and International Materials track. The course is offered every year in study period 4 for a total duration of 10 weeks with 50% day-time teaching. The language of instruction is English. Topics dealt in the course are related to contemporary issues in research and development of advanced materials for aerospace applications, addressing three main aspects: damage in Fiber Reinforced Polymer Composite (FRPC) materials; technologies for multi-material joints; manufacturing and characteristics of advanced metal alloys.

1.2. Student profile

Students attending the *Aerospace Materials* course are advanced-level students who hold a Bachelor degree or have an equivalent level of study. They have already attended 3 study periods of Master-level courses devoted to different advanced aspects of Materials Science and Engineering. Courses offered in study period 4 as the *Aerospace Materials* course are the last in which students learn in an instructor-guided setting, before spending the last year of study doing individual project work in the Materials Science and Engineering Project Course (30 credits) and the final Degree Project (30 credits). Students are thus expected to have a solid backgroud in the foundational subjects, such as Mathematics, Physics, Computational Science, Solid Mechanics. Their attendance to the course (being elective and not compulsory) is motivated by interest in the topics proposed. Furthermore, students' background is highly international with many of them (often the majority of attendees) foreigners. Swedish students attending the course have usually already spent time abroad at this point of their study path. Usually 10-15 students attend the course.

1.3. Programme goal and objectives

The goal of the Master Programme in Materials Engineering is stated to be[1]:

> *to educate only the very best students to a level where they can either continue and get a PhD-degree in a very short period of time or seek prestigious employment anywhere in the world*

while the goal of the Master Programme in Composite Materials states that[2]:

[1] LTU Catalog, Master Programme in Materials Engineering
[2] LTU Catalog, Master Programme in Composite Materials

this master program in materials technology will provide you with a unique competence in important aspects of composites manufacturing and design technologies. The education is strongly connected to companies such as Swerea SICOMP and ABB Composites who have announced a need for composite experts.

These overall goals are specified by a set of learning objectives which is shared by both programmes[3][4]:

for a Master of Science (120 credits), major Materials Engineering the student shall have:

- *demonstrated very good knowledge in materials engineering and materials science,*
- *demonstrated a strong background for research and development work in materials engineering and materials science related fields,*
- *demonstrated very good skills in oral and written presentations of scientific and technical materials in English,*
- *demonstrated ability for collaboration.*

In the case of the Programme in Composite Materials, two further objectives are added:

. . . the student shall have:

- *demonstrated very good knowledge in Polymer Composite Materials,*
- *demonstrated a strong background for research and development work in design and manufacturing technologies of Polymer Composite Materials.*

[3]LTU Qualification descriptor, Master Programme in Materials Engineering
[4]LTU Qualification descriptor, Master Programme in Composite Materials

By using the ABCD (Audience, Behaviour, Condition, Degree) and S.M.A.R.T. (Specific, Measurable, Achievable, Relevant, Time-Oriented) models [5, 6, 7], it is possible to observe that the objectives appear to be poorly phrased. In particular, the behavior is not expressed in a specific and measurable manner: it is always expressed by the use of "the student shall have demonstrated" followed by a noun describing knowledge ("knowledge","background","skills","ability") specified by a generic non-measurable attribute ("very good","strong"). They seem however to aim quite clearly at the highest levels of the taxonomies, those that correspond to an independent actor of the field who shoud be able to "get a PhD-degree in a very short period", "seek prestigious employment anywhere in the world" in " companies such as Swerea SICOMP and ABB Composites" or become a "composite expert".

In support of this view, objectives defining the level of Master of Science/Arts are reported in both two Programmes' list of objectives from the Higher Education Ordinance:

> *Knowledge and understanding*
> *For a Master of Arts/Science (120 credits) the student shall have:*
>
> - *demonstrated knowledge and understanding in the main field of study, including both broad knowledge of the field and a considerable degree of specialised knowledge in certain areas of the field as well as insight into current research and development work, and*
> - *demonstrated specialised methodological knowledge in the main field of study.*
>
> *Competence and skills*
> *For a Master of Arts/Science (120 credits) the student shall have:*
>
> - *demonstrated the ability to critically and systematically integrate knowledge and analyse, assess and deal with complex phenomena, issues and situations even with limited information,*

- *demonstrated the ability to identify and formulate issues critically, autonomously and creatively as well as to plan and, using appropriate methods, undertake advanced tasks within predetermined time frames and so contribute to the formation of knowledge as well as the ability to evaluate this work,*
- *demonstrated the ability in speech and writing both nationally and internationally to report clearly and discuss his or her conclusions and the knowledge and arguments on which they are based in dialogue with different audiences, and*
- *demonstrated the skills required for participation in research and development work or autonomous employment in some other qualified capacity.*

Judgement and approach
For a Master of Arts/Science (120 credits) the student shall have:

- *demonstrated the ability to make assessments in the main field of study informed by relevant disciplinary, social and ethical issues and also to demonstrate awareness of ethical aspects of research and development work,*
- *demonstrated insight into the possibilities and limitations of research, its role in society and the responsibility of the individual for how it is used, and*
- *demonstrated the ability to identify the personal need for further knowledge and take responsibility for his or her ongoing learning.*

1.4. Course objectives and learning outcomes

Course objectives and learning outcomes are detailed in its online syllabus[5]:

[5]Course syllabus, Aerospace Materials 7.5 Credits

After the end of this course the student is supposed to

- *have deep knowledge about structure and behaviour of high performance materials used in aerospace industry;*
- *be able to evaluate properties of composites, ceramic materials and alloys to perform optimal material selection for use in harsh environments and service conditions;*
- *know and understand the most important degradation mechanisms that initiate and evolve due to thermal and mechanical loads and lead to material fatigue and reduced durability;*
- *be able to produce long fiber composites, to measure their mechanical properties, to observe and to quantify damage modes and to analyse their effect on properties;*
- *be able to apply composite material degradation models, to perform fracture mechanics analysis in alloys and to predict time dependent material behaviour;*
- *be able to perform numerical simulations of structures using commercial software to design optimized structures;*
- *have good skills in analysing research papers and writing research reports.*

Course learning outcomes appear to be better structured and thought-through than programme outcomes. Both the cognitive (“knowledge about”,“analysing research papers”) [8, 9] and the psychomotor [10] taxomonies (“produce”,“measure”,“perform”) are addressed and verbs gradually reaching the higher levels of the taxonomies are used (“understand”,“evaluate”,“apply”). The course learning outcomes thus appear to be aligned with the programme outcomes and goal, which pointed to the student’s development into an independent professional figure in the field of materials engineering. At the course level, the competencies of this figure are specified in terms of the cognitive and psychomotor skills required to perform independent tasks of characterization and modeling of advanced materials for aerospace applications.

1.5. Course structure and activities

The course is thematically divided in 3 parts, which are treated in parallel under the direction of 3 different professors and the intervention of another 4-5 instructors: damage in composites, worth 65% of the time allotted and of the final grade; mechanics of adhesive hybrid joints, 10% of learning time and final grade; advanced alloys and ceramics, worth 25% of learning time and final grade. The design of teaching activities of each of the three parts is described in the following.

Damage in composites. The *Damage in composites* section represents the main part of the course, in which several different activities are conducted. First, topics are introduced in class during frontal lectures, in which the teacher uses a mix of oral presentation, slides with informative pictures and writing on the blackboard. Students are thus involved in both passive and active activities (ICAP, [11]): listening to the instructor and watching the presentation (*passive*) as well as note-taking and quick back-of-the-envelope calculations (*active*). Students are divided in groups of 6-7 students and assigned the same project. The project is presented only in a draft format at the beginning of the course, supposedly to mimic the evolution of a research project. At each lecture, a specific task of the project is outlined in detail through step-by-step instructions. Furthermore, the theory related to the task is introduced and explained in the same lecture and all the main equations and relations needed to complete the task are provided. The project involves several tasks of different nature: application of analytical models through general-purpose (Excel, Matlab) as well as dedicated software (LAP); manufacturing and testing of Fiber-Reinforced Polymer Composites; experimental data reduction and comparison with analytical predictions; numerical simulation with the Finite Element Method (FEM) using commercial softwares (Abaqus, Ansys).

The work is the same for each group and students are asked to hand in a final report of 30-50 pages at the end of the course. However, the evolution of the work is monitored through weekly seminars in which students present the state of the work together with problems, issues and obstacle to the advancement. These are discussed with all the course participants under the supervision of the instructor. All types of activities as enviosioned by the ICAP framework are considered in the project: reading assigned and suggested papers, revise course notes and slides, reading manufacturing and testing procedures (*passive*); highlighting useful project-related information, manufacturing and testing; developing FEM models (*active*); proposing solutions based on results obtained, analyzing the merits of analytical models by comparison with experimental results, infer conclusions about the mechanical behavior of materials from numerical simulations (*constructive*); co-working and co-supervision during manufacturing and testing, co-development of numerical models and algorithms, writing of a shared report, discussion of issues faced (*interactive*). The project takes place during the first 7 weeks, with the 8^{th} and last dedicated to the writing of the final report. Attendance to lectures is not mandatory and an oral exam is supposed to take place at the end of the course. However, at the oral exam the instructor asks one question for each lecture missed. Full attendance thus implies no questions at the oral exam or, in other words, no oral exam. The work of this section of the *Aerospace Materials* course touches upon both the cognitive as well as the psychomotr domain. The format of lecture detailing project task's instructions with the related theory, equations and algorithms followed by group-based work reaches only a mid-level on the taxonomic scale: *applying* for the cognitive domain and *manipulation/precision* for the psychomotor one.

Mechanics of adhesive joints. This theme is the smallest among the three. It is treated through 2 frontal lectures, in which the teacher explains the main issues and technological solutions in the context of the mechanics of adhesive joints. Students are mostly *passive* during these 2 lectures [11], as the presentation is always aided by slides later uploaded on Canvas. Students are then divided into groups of 2-3 people and each group is assigned a scientifc article about the mechanics of adhesive joints. The group has to read, analyze and present the article to the rest of the class during a dedicated seminar day. After the presentation, a class-wide discussion of the presentation is conducted lead by the instructor. This seminar activity constitutes the assessment for this part of the *Aerospace Materials* course, as well as its closing session. The seminar task requires the student to move up along the ICAP scale [11], in fact they need to: read the article (*passive*); highlight key informations of the paper (*active*); analyze the article and compare it with the corresponding literature (*constructive*); debate the article in the group and agree on a shared analysis to be presented in class (*interactive*); debate with peers in class (*interactive*). The task points to a learning in the cognitive domain, and aims to the high level of *evaluation* as it asks students to analyze and criticize a scientific article and defend the conclusions of the analysis in front of peers. Notice that assessment is based only on the presentation to the class and on the answers provided provided singularly (not group-wise) to the questions asked by the teacher.

Advanced alloys and ceramics. A series of 5 lectures takes place in this thread, each one devoted to a specific class of materials in the family of advanced alloys and ceramics. Lectures are frontal, with the teacher presenting the topic with the aide of slides later uploaded to Canvas. Students are thus mostly *passive* during the lectures [11]. Students are then divided in groups of 2-3 and assigned a group-wise seminar task. 2 groups are assigned to the same topic. Each one of these two groups needs to investigate the same question about a class of materials and provide a report. The report is then submitted to the other group. Each member of the group has to review the report and prepare an opposition in the form of a short report to be handed to the teacher on the seminar day. On seminar day, each group has to come prepared to present their findings and thus have also all the necessary supporting material (usually slides). Then, one of the two groups is extracted randomly to present; the other one will instead be the ooponent. After course day, all the presentations are uploaded on Canvas to be used as study material. The seminar task has a good balance of acitivities according to the ICAP framework [11]: *passive*, like reading scientific papers and textbooks on the topic and the other group's report; *active*, like highlighting and extracting relevant information from sources and finding relevant points in the reviewed report; *constructive*, as they need to develop a scientifically based answer to the seminar question and develop counter-arguments to the other group's report; *interactive*, in the development of the group's report and presentation and in the seminar day discussion. The task reaches the higher level of the cognitive taxonomy, as students are asked to: develop an essay in which they answer an issue of current interest in the field based on the available scientific literature; evaluate and criticize the other group's work; debate the findings and argue for their choices. Assessment takes place during seminar preparation (hand-in of reports and reviews) and seminar day. Furthermore, students are asked to sit a closed-books written exam on this section of the course with open-ended questions on the topics treated (comprising the seminar).

A Canvas room exists for this course. It consists of a single page with links to the lectures' slides, organized in 3 sections according to the thematic division of the course. There is no reference to the pedagogical team, to the course structure, learning outcomes, no clear description of assessment. The Canvas room works almost exclusively as a repository of files (slides, raw data, examples of numerical models, assigned and suggested readings) and for sporadic email exchanges to organize the different laboratory sessions.

1.6. An issue of constructive (mis)alignment

A misalignment between course design and course outcomes and between the different thematic sections of the course seems to be present. Course outcomes, in alignment with programme outcomes, envision a student who is able, at the end of the *Aerospace Materials* course, to undertake an independent research project under the supervision of the University research staff. The student is thus expected to be able to:

1. read, analyze and criticize the scientific literature;
2. investigate the state-of-art in the field to understand which questions still need to be answered;
3. propose experimental designs and numerical models to verify hypothesis based on examples in the literature;
4. successfully perform the experiments and construct the numerical models;
5. independently derive analytical models and results starting from the information provided in scientific articles;
6. compare the predictions of different models with experimental measurements and derive conclusions about the behavior of materials.

Thus, the high levels of the taxonomies need to be addressed. The first two sets of skills are addressed at a high taxonomic level [8, 9, 10] in the *Mechanics of adhesive joints* and *Advanced alloys and ceramics* sections of the course. The rest of them should be addressed in the *Damage in composites* section: however, activities proposed here focus on the mid-level of the taxonomies, i.e. reception, understanding and application of knowledge [8, 9]. There is consequently a misalignment: the high taxonomic level expected is not achieved and the corresponding learning outcomes and objectives are not fulfilled.

1.7. Students feedback

To verify the previous conclusions and gain more insights on the effectiveness of the current structure of the *Aerospace Materials* course, two students[6]

[6]Lena Brunnacker and Pauline Leonard. The author thanks them for their time and help.

were interviewed. They attended the course in SP 4 of year 2018 respectively as part of the Master Programme in Composite Materials and of the Master Programme in Materials Science & Engineering (EEIGM). Here is a summary of their feedback on the course, with a focus on the *Damage in composites* section.

- The project in composite damage is very interesting and should be kept;
- organisation is lacking: no clear deadlines, the project tasks are not clearly outlined from the beginning of the course;
- groups for the project in composite damage should be smaller (3-4 students) and randomly selected, as people tend to stay with those they know to the disadvantage usually of foreign and exchange students;
- seminars as a moment to exchange ideas between groups are a good idea, but should be used more deeply and not only to show the results as it has been done;
- lectures are hard to follow;
- formulas and equations explained during lectures are applied to the resolution of the project task without any real learning of the assumptions, principles and derivation methods;
- no proposed article was read as time was scarce and there was no clear connection beween reading the articles and completion of project tasks;
- tutorials about the software used should be provided earlier in the course;
- work in groups was divided among the members based on their background and previous experience, thus students who already knew the software and methods worked with them.

The misalignment previously described is confirmed by the students' comments: articles are not read because the need for them is not clear; lectures are hard to follow and the models presented are applied to the s olution of the project without learning them; interaction with peers is useful and welcome but should be deeper; no real learning of the software and tools proposed takes place because work is subdivided among group members in the way that best fits the time-constraint, i.e. assigning the task to those who already know how to solve it.

2. A flipped-learning design of the Damage in composites section of the Aerospace Materials course

2.1. The flipped classroom approach and the engineering signature pedagogy

In the previous section, a misalignment between learning outcomes and the implemented learning activities has been identified in the *Damage in composites* section of the course. Thus, a new design is proposed in this section to solve the identified issue based on the flipped learning approach.

The flipped learning apporach is a form of learning design in which what in a traditional setting happens inside the class is moved outside it (and viceversa) [12], which implies a change of the role of the teacher from the source of knowledge ("the sage on stage") to a coach guiding and supporting the learning process ("the guide on the side") [13]. Recent advances in Information and Communication Technologies (ICTs) have helped the implementation of flipped classroom settings, and different examples are available in the literature about its use in engineering and higher education in general. Recent reviews [14, 15, 16] have pointed out that, although quantitative statistically significant evidence is scarce that flipped learning has any effect on students' academic performance, its implementation in different formats always favors higher-order learning in the classroom and uses outside-the-classroom time for low-level processing of information. This in turn translated in greater engagement by the studens and by increased students' confidence in tackling critical thinking tasks in the academic and work environments. Examples of the application of flipped learning designs in engineering education (biomedical [17], mechanical [18] and civil [19] engineering) show some common traits:

- the teacher is no longer explaining the theory (principles, theorem, equations, formulas) in class with the help of the blackboard and eventually slides;
- the explanation of the theory is recorded in videos where the teachers presents principles, theorem, equations, formulas with the use of a virtual or real blackboard and slides;
- students can access the videos through the course Learning Management System (LMS), where they can also found additional supporting material in the form of slides, tutorials, compendia;
- in-class time is devoted to students' questions and to problem-solving activities, usually calculation-based problems similar to those appearing in the final exam;
- problems are selected in order to provide a professional perspective to the course topics (real-life scenarios, issues of current interest, ...) and they might be used to promote discussions between students.

Such designs are a literal application of the description of flipped learning design as found in [12]: what was done in class (teacher explaining theory using the blackboard and slides) is moved to outside the classroom (videos and slides available on the course LMS), while the activities previously done outside the classroom (solving exercises in preparation of the final exam) are now done in class under the guidance and help of the teacher (in-class problem-solving activities). Given that one aspect on the engineering profession is undoubtely the ability to apply theoretical knowledge to the resolution of design, verification, estimation and prediction problems, the implementation suggested in [17, 18, 19] certainly fosters a deep learning approach to problem-solving which in the classic setting is too often demoted to an exam preparation task, frequently removed from students' interests and professional perspectives (closed problems with an exact solution far away from the open-ended design problems engineers usually face). However, I argue that these examples still miss a critical aspect of engineering education, which is present in the deep structure of the engineering signature pedagogy [3]. Engineering, especially specializations like mechanical, aerospace, materials, biomedical, civil, is characterized by a wide and deep body of theoretical knowledge built on physical principles and mathematical mastery. This core theoretical knowledge is built around the threshold concepts [4] of *model* and *accuracy*: the idea that, given a specific set of physical, technical, economical and safety constraints, it is possible to develop a set of equations or algorithms with which it is possible to predict the behavior of the system under study to a certain accuracy and design repeatable and controlled human interventions upon it. Accuracy is the second key term: a model provides a prediction with a certain margin of error which can be evaluated by means of experiments, analytical derivations and numerical simulations. Accuracy, together with considerations of economical and technical feasibility, determines which model is used for a specific purpose. Let us discuss an example to clarify these concepts. The motion of a satellite can be predicted by means of different models (based on different physical principles and using different mathematics). A first model that can be used is Newtonian mechanics, based on the work of Newton in the 1600s. A second model that can be used is general relativity, grounded in the results derived by Einstein in the 1900s. Which one is most commonly used to design satellite orbits in industry? Newtonian mechanics (!). Why? Because the increase in accuracy provided by the use of general relativity does not outweigh the increase in time and resources (computers need electricity!) needed to compute the solution. It is important to notice that this is the typical mindset of engineers: physicists, on the other hand, regard general relativity as a step further in the understanding of the world, which holds a higher degree of truth with respect to previous theories like Newtonian mechanics. Learning of these threshold concepts and the development of the engineering mindset is embedded in the deep structure of classic engineering signature pedagogy, as exemplified in Table 1.

In the signature pedagogy described in Table 1, in steps 1-4 student activ-

Table 1: Surface and deep structure of classic engineering signature pedagogy.

	Surface structure		Deep structure
	Who	*What*	
	Where	*How*	
1.	teacher	introduces the system (physical, chemical, biological) to be investigated	definition of the design, verification, estimation or prediction problem
	in class	pictures, videos, slides, artifacts	
2.	teacher	introduces constraints and assumptions	definition of physical, technical, economical and safety constraints
	in class	blackboard, slides	
3.	teacher	introduces governing physical principles and corresponding mathematical laws	foundational physical principles governing the system
	in class	blackboard, slides	
4.	teacher	by applying assumptions and constraints to governing laws, derives predictive formulas and algorithms	development of formulas and algorithms for estimation and prediction
	in class	blackboard, slides	
5.	students	solve problems by application of the derived predictive formulas	application of derived formulas to the quantitative estimation of system behavior
	outside class	pen and paper, computer	
6.	students	verify model's accuracy by conducting experiments	verification of model accuracy by means of experiments
	lab	testing equipment, computer	

ities can be classified as *passive* (mostly listening to the teacher and watching slides) and *active* (mostly note-taking following the teacher's mathematical derivations at the blackboard) according to ICAP framework [11]. It is worth to notice that in the engineering signature pedagogy, the threshold concepts of model and accuracy together with the conceptual tools to use them (assumptions, first principles, mathematical derivations) are learned through *imitation*, i.e. the students following the derivations of the teacher at the blackboard and writing notes at the same time. Problem-solving is instead at the *constructive* level of the ICAP scale in the classic engineering pedagogy, as students transfer the concepts derived in class by the teacher at the blackboard and noted down (*passive-active*) to new situations (problems to solve). The flipped learning approach as implemented in [17, 18, 19] manages to bring the problem-solving task to the *interactive* level, by moving it inside the classroom and using group-based activities to promote discussion. However, it demotes at the same time the learning of the theory (points 1-4 in Table 1) to a purely *passive* level by using videos, slides and compendia available on the LMS.

I present here a different approach to the flipped classroom in engineering education, which takes into account the signature pedagogy of engineering previously described. Instead of moving activities 1-4 (Table 1) outside and 5 inside the class, steps 1-4 are gradually moved outside the class until only activity 1 is retained inside the classroom (which has a strong link with professional life: the design problem is often assigned by some external stakeholder). Furthemore, step 5 (problem-solving) is moved only in part inside the class in close relationship with activity 6 (experimental verification).

In Section 2.2, a new formulation of course goal and learning outcomes is proposed for the revised design of the *Aerospace Materials* course. In Section 2.3 an outline of the learning activities is suggested based on a weekly planning. Activities are categorized as

in class: activities that take place inside the classroom under the guidance, supervision and/or collaboration of the instructor;

laboratory: activities taking place in the mechanical testing laboratory, i.e. experimental sessions;

outside class: student learning activities happening outside the class and the laboratory and not requiring the use of the online LMS (although not strictly excluding it, for example in a review for exam preparation);

online LMS (Canvas): activities that require the interaction with the online LMS (Canvas), like videos, quizzes, webpages, ...

Furthermore, it is highlighted which type of assessment and consequent feedback is envisioned for the activities of each week. Finally in Section 2.4 a brief discussion of the risks of the flipped-classroom design is proposed.

2.2. Course goal and learning outcomes

Course goal. On successful completion of the *Aerospace Materials* course, the student will be able to undertake an independent research project in the field of Materials Science & Engineering under the supervision of University research staff either independently or as part of a small team.

Course learning outcomes. Upon completion of the 10-weeks *Aerospace Materials* course, the student in the Master Programmes in Materials Engineering, Composite Materials and Materials Science & Engineering (EEIGM) will be able to:

1. independently search, read, analyze and criticize the scientific literature;
2. discuss and compare with colleagues and agree on shared conclusions upon the relevance of results available in the literature with respect to the research question investigated;
3. given observations about the behavior of a composite material, independently: identify and analyze the relevant constraints, formulate

assumptions and justify them with physically-based arguments, recall and select the relevant first principles, develop predictive formulas and algorithms based on the correct application of mathematical methods selected on purpose (analytical or numerical);

4. independently implement and calibrate the predictive formulas and algorithms (analytical or numerical) and produce quantitative predictions of material behavior;
5. independently construct an experimental design to gather results relevant to the research question investigated based on designs available in the scientific literature;
6. discuss, compare and agree on a common experimental design with colleagues;
7. perform manufacturing and testing of composite specimens according to internationally recognized ASTM standards;
8. compare models of material behavior with the experimental results, evaluate their accuracy and applicability;
9. produce in collaboration with peers a written report amenable to be submitted to a peer-reviewed journal or distributed as an internal research report;
10. independently defend the results and conclusions proposed in a dialogic setting.

ABCD and SMART criteria analysis. For all learning outcomes:

→***A*udience**: the student in the Master Programmes in Materials Engineering, Composite Materials and Materials Science & Engineering (EEIGM); *S*pecific.

→***C*ondition**: Upon completion of the 10-weeks *Aerospace Materials* course; *T*ime-oriented, *S*pecific, *A*chievable, *M*easurable.

1. →***B*ehavior**: search, read, analyze and criticize the scientific literature; *S*pecific, *R*elevant; *Cognitive domain, evaluation level (verb: criticize).*

   →***D*egree**: independently; *S*pecific.

2. →***B*ehavior**: discuss and compare ... and agree on shared conclusions upon the relevance of results available in the literature; *S*pecific, *R*elevant, *A*chievable; *Cognitive domain, Analysis level (verb: compare).*
   →***C*ondition**: with colleagues; *S*pecific.
   →***D*egree**: with respect to the research question investigated; *S*pecific, *R*elevant.
3. →***B*ehavior**: identify and analyze the relevant constraints, formulate assumptions and justify them with physically-based arguments, recall and select the relevant first principles, develop predictive formulas and algorithms based on the correct application of mathematical methods selected on purpose (analytical or numerical); *S*pecific, *R*elevant, *A*chievable, *M*easurable; *Cognitive domain, Creation level (verb: formulate, develop).*
   →***C*ondition**: given observations about the behavior of a composite material; *S*pecific, *R*elevant.
   →***D*egree**: independently; *S*pecific, *R*elevant.
4. →***B*ehavior**: implement and calibrate the predictive formulas and algorithms (analytical or numerical) and produce ... predictions of materials behavior; *S*pecific, *R*elevant, *A*chievable, *M*easurable; *Cognitive domain, Application level (verb: implement, produce)* and *Psychomotor domain, Precision level (verb: calibrate).*
   →***C*ondition**: quantitative; *S*pecific, *R*elevant, *M*easurable.
   →***D*egree**: independently; *S*pecific, *R*elevant.
5. →***B*ehavior**: construct an experimental design to gather results; *S*pecific, *R*elevant, *A*chievable; *Cognitive domain, Creation level (verb: construct).*
   →***C*ondition**: based on designs available in the scientific literature; *S*pecific, *R*elevant, *M*easurable.
   →***D*egree**: independently; *S*pecific, *R*elevant.
   relevant to the research question investigated; *R*elevant.
6. →***B*ehavior**: discuss, compare and agree on a common experimental design; *S*pecific, *R*elevant, *A*chievable; *Cognitive domain, Analysis level (verb: compare).*
   →***C*ondition**: with colleagues; *S*pecific.

7. →***B*ehavior**: perform manufacturing and testing; *S*pecific, *R*elevant, *A*chievable, *M*easurable; *Psychomotor domain, Precision level (verb: perform).*
   →***C*ondition**: of composite specimens; *S*pecific, *R*elevant, *M*easurable.
   →***D*egree**: according to internationally recognized ASTM standards; *S*pecific, *R*elevant, *M*easurable.
8. →***B*ehavior**: compare models of material behavior . . . , evaluate their accuracy and applicability; *S*pecific, *R*elevant, *A*chievable, *M*easurable; *Cognitive domain, Evaluation level (verb: compare, evaluate).*
   →***C*ondition**: with the experimental results; *S*pecific, *R*elevant, *M*easurable.
9. →***B*ehavior**: produce a . . . report; *S*pecific, *R*elevant, *A*chievable, *M*easurable; *Cognitive domain, Creation level (verb: produce).*
   →***C*ondition**: written; *S*pecific, *M*easurable.
   in collaboration with peers; *S*pecific, *R*elevant.
   →***D*egree**: amenable to be submitted to a peer-reviewed journal or distributed as an internal research report; *S*pecific, *R*elevant, *A*chievable.
10. →***B*ehavior**: defend the results and conclusions proposed; *S*pecific, *R*elevant, *A*chievable; *Cognitive domain, Evaluation level (verb: defend).*
    →***C*ondition**: in a dialogic setting; *S*pecific, *R*elevant.
    →***D*egree**: independently; *S*pecific, *R*elevant.

2.3. Outline of learning activities and assessment

In-class meetings are assumed to take place at the very beginning of the week (Monday morning). Estimated hours of work for an individual student are reported in parenthesis. The workload has been calculated to be roughly equal to 65% of a 7.5 credits course ($\sim 130 - 136$ hours in total) and spread evenly over 10 weeks. Weeks 9 and 10 are reserved for personal study in preparation to the final exam and for the final oral exam itself. Personal study time is counted towards the total of $\sim 130 - 136$ hours. The use of Latex is required for all written assignments (a tutorial is provided during the first week).

Week 1 - 17 h

In class	(1 h) - Teacher introduces course goal and learning outcomes, organization, structure and planning. Teacher introduces the research question of the course (each year a new one), its relevance in the aerospace field, examples from industry and previous research. Supporting material is used like slides, pictures, videos. A few scientific articles are suggested by the teacher. The teacher communicates to the students the structure of the project groups for team-based work. Group members are selected randomly.
Laboratory	

Outside class	(13.5 h) - Students conduct an individual survey of the scientific literature around the research question introduced in class. The guiding questions are: what experimental knowledge is available? what experiments were conducted? How were experiments conducted? What models (analytical and numerical) exist for this phenomenon? What is the accuracy of each one? They are asked to produce a commented list of references: for each reference, they should summarize the relevant content in 2-3 sentences. The commented list of reference is submitted through Canvas. (0.5 h) - Students conduct a peer-review of the commented list of references on one colleague's work. Students of different groups are matched together.
Online LMS (Canvas)	(1 h + 1 h) - One interactive tutorial on Latex and one interactive tutorial on Abaqus. Tutorials are fully web based, with step-by-step explanations followed by small coding exercises. Successful completion of an exercise unlocks the subsequent one[7]. Hints are provided and devoted discussion threads on the forum are created, where both students and teacher(s) participate. Tutorials are individual and are personalized (different data, small changes in the geometry,...) through an automatic algorithm.
Assessment	*Individual*: the commented list of references and the two online interactive tutorials. *Group*: none.

[7]A freely-accessible example can be found at freeCodeCamp.

Feedback	Written peer- and instructor-feedback on the commented list of references.
Week 2 - 17 h	
In class	(4 h) - Students work with their project group starting from the commented list of references and the feedback received on it. The first objective is to produce a commented table of contents for a *state of the art review* section by selecting which experimental methods to recall and describe, and which models (analytical and numerical) to mention and discuss. The commented table of contents contains title, subtitles, a summary in a few sentences (2-4) of each subsection's content and the list of references pertaining to it. The commented table of contents is submitted through Canvas by the end of the session. The instructor guides and supports the work of the groups. (2 h) - The second objective is to select, starting from the work on the commented table of contents, the 3 analytical models from the literature that seems the best to answer the research question. The in-class activities are closed by a class-wide discussion on the choice of the 3 analytical models. With the help of the instructor, a final common choice of 3 models is made.
Laboratory	
Outside class	(1 h) - Students conduct a peer-review of the commented table of contents on another group's work. The peer-review is individual.

	(7 h) - After the reception of feedback on the commented table of contents, students work in group to produce a draft version of the *state of the art review* section of the final report. The draft is submitted on Canvas.
Online LMS (Canvas)	(1 h + 1 h + 1 h) - One interactive tutorial on Matlab, one interactive tutorial on Excel and one interactive tutorial on Abaqus (see Week 1 for details about their structure).
Assessment	*Individual*: the three online interactive tutorials. *Group*: the commented table of contents, the draft *state of the art review* section.
Feedback	Oral instructor-feedback during in-class activities. Written peer- and instructor-feedback on the commented table of contents. Written instructor-feedback on the draft *state of the art review* section.

Week 3 - 9.5 h

In class	(1 h) - Of the 3 models defined in the previous week, the first is treated. The teacher introduces the system, introduces constraints and assumptions and the governing physical principles with the corresponding mathematical laws (steps 1 to 3 of the engineering signature pedagogy, see Table 1).
Laboratory	
Outside class	(2 h) Students work individually on the model introduced and, by applying assumptions and constraints to the governing laws, derive predictive formulas and algorithms (step 4 of the engineering signature pedagogy, see Table 1). They submit their work on Canvas. (1 h) Students proceed to an individual peer-review of another colleague's work on the analytical model.

	(1 h) Given the properties of constituents (fiber and matrix), students estimate individually the elastic properties of the composites using micromechanical models. (1 h) Students proceed to an individual peer-review of another colleague's work on the elastic properties estimation.
Online LMS (Canvas)	(1 h +1 h + 1.5 h) One interactive tutorial on Abaqus (see Week 1 for details about their structure). Videos and online readings (Canvas pages) on manufacturing and testing of composites. Optional: interactive course (review) of micromechanical evaluation of elastic properties of composites (topic of a course in the previous study periods).
Assessment	*Individual*: the submission on the analytical model and the on the elastic properties estimation, the online interactive tutorials, online quiz on manufacturing and testing of composites. *Group*: none.
Feedback	Written peer- and instructor-feedback on the submission on the analytical model and the on the elastic properties estimation.

Week 4 - 16.5 h

In class	(2 h) Based on the work of the previous week, students work with their project group and start writing the *Theory* section of the report by summarizing the first model with relevant mathematical derivations and reference articles. The instructor guides and supervises the work of the groups. The new report section is submitted on Canvas by the end of the session.

	(2 h) Working with their project group, students apply the first analytical model to predict the experimental tests' results using the material properties evaluated in the previous week. Geometry is given and is the same of the specimens manufactured during the same week. The instructor guides and supervises the work of the groups. (2 h) Working with their project group, students develop the first (of two) numerical model in Abaqus using the material properties evaluated in the previous week. Geometry is given and is the same of the specimens manufactured during the same week. The instructor guides and supervises the work of the groups. (1.5 h) Working with their project group, students define an experimental procedure to evaluate the elastic properties of composite laminates starting from the references gathered in Week 1. The instructor guides and supervises the work of the groups. An experimental procedure common to the whole class is agreed through a class-wide discussion lead by the instructor. (0.5h) Of the 3 models defined in the previous week, the second is treated. The teacher introduces the system and constraints and assumptions (steps 1-2 of the engineering signature pedagogy, see Table 1).
Laboratory	(4 h) In group: manufacturing, cutting and polishing of specimens, gluing of tabs and of strain gauges (if needed).
Outside class	(1 h) - Students conduct a peer-review of the *Theory* section of another group. The peer-review is individual.

(2.5 h) Students work individually on the model introduced and, by formulating assumptions and constraints and applying them to the governing laws, derive predictive formulas and algorithms (step 3-4 of the engineering signature pedagogy, see Table 1). They submit their work on Canvas.

(1 h) Students proceed to an individual peer-review of another colleague's work on the analytical model.

Online LMS (Canvas)

Assessment — *Individual*: the submission on the analytical model.
Group: the *Theory* section of the report.

Feedback — Written peer- and instructor-feedback on the submission on the analytical model. Written peer- and instructor-feedback on the *Theory* section of the report. Oral instructor feedback on the application of the analytical model, the development of the numerical model and the definition of the experimental procedure.

Week 5 - 15 h

In class — (2 h) Based on the work of the previous week, students work with their project group and continue writing the *Theory* section of the report by summarizing the second model with relevant mathematical derivations and reference articles. The instructor guides and supervises the work of the groups. The updated report section is submitted on Canvas by the end of the session.

	(2 h) Working with their project group, students apply the second analytical model to predict the experimental tests' results using the material properties evaluated in Week 3. Geometry is given and is the same of the specimens manufactured during the previous week. The instructor guides and supervises the work of the groups.
	(2 h) Working with their project group, students develop the second numerical model in Abaqus using the material properties evaluated in the Week 3. Geometry is given and is the same of the specimens manufactured during the previous week. The instructor guides and supervises the work of the groups.
	(1.5 h) Working with their project group, students define an experimental procedure to estimate the level of damage of composite laminates starting from the references gathered in Week 1. The instructor guides and supervises the work of the groups. An experimental procedure common to the whole class is agreed through a class-wide discussion lead by the instructor.
	(0.5h) Of the 3 models defined in the previous week, the third is treated. The teacher introduces the system (steps 1 of the engineering signature pedagogy, see Table 1).
Laboratory	(2 h) In group: testing of specimens to evaluate elastic properties. Raw data are uploaded to Canvas and shared with the other groups.
Outside class	(1 h) - Students conduct a peer-review of the *Theory* section of another group. The peer-review is individual.

(3 h) Students work individually on the model introduced and, by identifying constraints, formulating assumptions and applying them to the governing laws, derive predictive formulas and algorithms (step 2-4 of the engineering signature pedagogy, see Table 1). They submit their work on Canvas.

(1 h) Students proceed to an individual peer-review of another colleague's work on the analytical model.

Online LMS (Canvas)

Assessment — *Individual*: the submission on the analytical model.
Group: the *Theory* section of the report.

Feedback — Written peer- and instructor-feedback on the submission on the analytical model. Written peer- and instructor-feedback on the *Theory* section of the report. Oral instructor feedback on the application of the analytical model, the development of the numerical model and the definition of the experimental procedure.

Week 6 - 23 h

In class — (2 h) Based on the work of the previous week, students work with their project group and continue writing the *Theory* section of the report by summarizing the third model with relevant mathematical derivations and reference articles. The instructor guides and supervises the work of the groups. The updated report section is submitted on Canvas by the end of the session.

(2 h) Working with their project group, students apply the third analytical model to predict the experimental tests' results using the material properties evaluated in Week 3. Geometry is given and is the same of the specimens manufactured during Week 4. The instructor guides and supervises the work of the groups.

(2 h) Working with their project group, students analyze the raw data gathered in Week 5 and provide estimations of the elastic properties of the composite material studied. The instructor guides and supervises the work of the groups.

Laboratory (16 h) In group: testing of specimens to evaluate damage. Raw data are uploaded to Canvas and shared with the other groups.

Outside class (1 h) - Students conduct a peer-review of the *Theory* section of another group. The peer-review is individual.

Online LMS (Canvas)

Assessment *Individual*: none.

Group: the *Theory* section of the report.

Feedback Written peer- and instructor-feedback on the *Theory* section of the report. Oral instructor feedback on the application of analytical models and the analysis of the experimental data.

Week 7 - 12 h

In class (2 h) Working with their project group, students analyze the raw data gathered in Week 6 and provide estimations of the evolution of damage of the composite material studied. The instructor guides and supervises the work of the groups.

	(1 h) Working with their project group, students calculate new analytical predictions using the 3 models adopted and the material properties evaluated from tests in Weeks 5-6. (1 h) Working with their project group, students calculate new numerical predictions using the 2 models developed and the material properties evaluated from tests in Weeks 5-6. (4 h) Working with their project group, students compare analytical and numerical predictions with experimental results, draw conclusions about the use of calculated vs measured elastic properties, evaluate the accuracy of the models used vs their ease of use. The students produce a draft version of the *Results and discussion* section of the report (title, subtitles, main graphs, logical passages summarized in 2-3 sentences), which is submitted on Canvas at the end of the session.
Laboratory	
Outside class	(2 h) Working with their project group, students write a draft version of the *Materials and Methods* section of the report, which is submitted on Canvas. (1 h) - Students conduct a peer-review of the *Materials and Methods* section of another group. The peer-review is individual. (1 h) - Students conduct a peer-review of the *Results and discussion* section of another group. The peer-review is individual.
Online LMS (Canvas)	
Assessment	*Individual*: none.

	Group: the *Materials and Methods* and *Results and discussion* sections of the report.
Feedback	Written peer- and instructor-feedback on the *Materials and Methods* and *Results and discussion* sections of the report. Oral instructor feedback on the analysis of experimental data and on the comparison between experimental, analytical and numerical results.
Week 8 - 14 h	
In class	(8 h) Working with their project group, students gather and review the work done in Weeks 1-7 and produce the final version of the report. The instructor guides and supervises the work of the groups.
Laboratory	
Outside class	(4 h) Working with their project group, students perform the final revision of the report, which is submitted on Canvas. (2 h) - Students conduct a peer-review of the report of another group. The peer-review is individual.
Online LMS (Canvas)	
Assessment	*Individual*: none. *Group*: graded assessment by the instructor of the final version of the report.
Feedback	Written peer- and instructor-feedback on the final version of the report. Oral instructor feedback on the preparation of the final version of the report.
Week 9 - 12 h	
In class	
Laboratory	
Outside class	(12 h) Individual study in preparation for the final exam.
Online LMS (Canvas)	

Assessment	*Individual*: none. *Group*: none.
Feedback	Written peer- and instructor-feedback on the final version of the report. Oral instructor feedback on the preparation of the final version of the report.

Week 10 - 0.5/1 h

In class	(0.5/1 h) Final individual oral exam. Discussion starts from the report together with the feedback received upon it and the personal work on the analytical models of Weeks 3-6. The student should show familiarity with the concepts, models and tools used; be able to justify the choices made throughout the project work; identify areas for improvement and suggest ideas for subsequent research.
Laboratory	
Outside class	
Online LMS (Canvas)	
Assessment	*Individual*: graded oral exam. *Group*: none.
Feedback	Oral instructor feedback on the performance in the oral exam.

2.4. Risks

→ Class size: the course is designed for a small class, i.e. a maximum of ~ 20 students. If more students register and actively attend the course, especially in-class activities could become hard to manage. A solution could be allowing more instructors inside the classroom. However, there will be a risk of noise and confusion which can lead to a loss in focus.

→ Respect of deadlines: many activities depend on the timely completion of the previous ones. If some students are late or miss some submissions, there might be some organisational problems. Especially critical are the peer-review feedback submissions, although they are always matched by an instructor feedback.

→ Workload- and evaluation- related stress. The workload has been calculated to be roughly equal to 65% of a 7.5 credits course ($\sim 130 - 136$ hours in total) and spread evenly over 10 weeks. However, students have reported very packed schedules during the course study period. To prevent the insurgence of workload- and especially evaluation-related stress in students which will hamper an effective learning, it is important to highlight during the course that weekly assessment is formative and counts only as pass/fail.

→ Technical issues: no material exists at the moment to support the envisioned Canvas activities. A strong effort is required to develop all the features described. Technical problems may likely arise and can prevent the successful completion of the tasks planned, thus hampering an effective learning experience.

→ Design of online tutorials: online tutorials are fundamental in providing the students with the technical skills to perform the tasks required for the report. They must ensure the correct acquisition of the necessary skills and techniques; otherwise, there is a risk that the time allotted for research tasks is not be enough (more training is needed by students) or an uneven division of labor takes place (those who already know do the work). Design of online tutorials is thus critical.

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