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FRAMEWORK FOR CRISIS-RESISTANT ENGINEERING PRODUCT DEVELOPMENT COURSES

Maximilian SCHRAMEK[1], Niccolò BECATTINI[2], Stanko ŠKEC[3], Nikola VUKAŠINOVIĆ[4], Manfred GRAFINGER[1] and Patrick ROSENBERGER[1]
[1]Technische Universität Wien, Austria
[2]Politecnico di Milano, Italy
[3]University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Croatia
[4]University of Ljubljana, Faculty of Mechanical Engineering, Slovenia

ABSTRACT
This paper proposes a framework for the systematic adaptation and digitalisation of engineering product development courses in the event of a crisis. Applicants can use resources of the framework to identify crisis-related boundary conditions that impact the delivery of education and are assisted in determining the necessary level of course digitalisation to respond to the crisis. Furthermore, the framework comprehends a review of modern educational teaching objectives, as well as a table containing tools and methodologies linked to educational targets. These can be used to enhance course design to keep students independently of their learning profiles engaged in study activities and to uphold an excellent knowledge acquisition in a volatile environment. An exemplary application of the framework on a CAD course in a higher education context guides the educator through the processes.

Keywords: Engineering education, crisis scenarios, crisis education, digitalisation, post COVID-19 transition

1 INTRODUCTION
The COVID-19 pandemic forces higher education institutions to a radical shift towards digitising teaching activities and materials. Despite the availability of plenty of educational tools and methodologies, the question of how lectures can be composed for virtual teaching while complying with restricting crisis conditions has not been systematically answered so far. Therefore, educators need to rely on their own digital competencies and the institution's resources rather than on scientifically justified and tested approaches. The ongoing crisis demands that courses are taught online in the foreseeable future, and this situation will likely not change even after the end of the crisis. Instead, a continued and even growing demand for digital education and blended learning approaches is expected. A framework for the systematic adaptation and digitalisation of engineering education courses in the event of a crisis is therefore proposed in this paper. It is designed to help find the most suitable approaches, thereby demanding general validity and broad applicability regardless of the application scenario. The differentiation between diverse crisis events is based on a set of boundary conditions that directly impact the realisable form of education. This prevents the unintentional focus on specific crisis events and ensures that future events can be classified. The framework also differentiates between various lecture types, allowing educators to match the presented approaches with their own courses, select the most suited ones and adapt the courses accordingly. To validate the framework, its usability will be tested as a part of regular product development courses, analysing feedback from educators and students of four European universities during the academic year 2021/22.
The paper presents an exemplary application of the framework on CAD courses, which are often composed of ex-cathedra lectures to impart general concepts of computer-aided design, in conjunction with tutorials to familiarise the student with CAD software. The example will show how the framework suggests educational approaches, methods and tools (educational items) to support each individual lecture type. Its recommended educational items enable a convenient matching with student learning styles, to enable a course design aligned with a modern student-centred learning approach.

2 PROPOSED APPROACHES

Aiming at developing a framework to answer the question of how design education can be adapted and digitalised in the event of a crisis, it is primarily important to understand how to describe crisis events and how to align course design with modern educational objectives (Section 2.1).

To determine a representing set of boundary conditions, which hinder the delivery of education and have general validity regardless of the type of event, an analysis of highly disruptive present and past crisis events has been conducted.

Then, as a starting point for the educational contents of the framework, common lecture and assessment types were defined by reviewing mechanical engineering study curricula in the higher education sector. Differentiating between lecture types allows educators to match the presented approach with their own courses. For the purpose of characterising the layout of a lecture type with respect to the degree of digitalisation, levels of technological support are introduced: from no technology to fully online lectures. This aids the educator to choose the appropriate digital lecture layout for their own course. Online learning is often attributed to a self-learning, text-based and passive environment: it is particularly difficult to provide educational services that facilitate different types of learners. Therefore, applicants of the framework are provided with an overview of modern educational objectives as well as a list of educational tools and methodologies based on "The Complete List of Teaching Methods" [1]. The items on the list have been reviewed with regard to their suitability for engineering education and assessed for their applicability to learning styles, lecture types and their respective levels of digitalisation in a two-step assessment round. In round one of the assessments, the authors of this study independently evaluated each item and proposed new product development specific items. Round two comprised a group discussion evaluating individual judgements, followed up by subsequent consensus-finding discussions (Sect 2.2).

2.1 Characterisation of crisis scenarios

To enable a generic description of disruptive crisis events, a set of characteristic crisis conditions is introduced. Crisis conditions can be grouped as either general, higher-education related or personal. **General crisis conditions** apply to the population within the affected area and are related to restrictions in mobility, the availability of electrical power and connectivity failures such as telephone or internet connections. **Higher-education related conditions** refer to the accessibility of institutional infrastructure, availability and accessibility of learning resources and educational personnel to deliver education. **Personal conditions** are restricted only to the equipment necessary to receive or deliver education. In addition, there is a variety of personal restrictions that can impact the ability to participate in education and training (e.g., motivation, personal capacity, etc.). This paper, however, is focused on methodologies and tools for crisis-resistant education and training. Therefore, person-specific psychological aspects that influence education are not considered. Depending on the severity of restricting crisis conditions (e.g., lockdown, travel ban), an educator is supported in choosing among physical, hybrid or completely-online teaching modes. A list of generic crisis conditions with varying degrees of severity provides the educator with assistance while assessing the severity of the crisis event. The list can be found online on www.cresdet.eu.

2.2 Educational design

The emergence of a crisis, whatever its scenario is, requires the educators to rethink the delivery of the course with reference to its Intended Learning Outcomes (ILOs). These are typically predefined, especially if the course is already in place before the crisis emerges. However, depending on the scenario at hand, the ILO should be revised and appropriately defined. The (revised) Bloom's Taxonomy [2] can be used as a target reference for this purpose, as it categorises educational goals into six major categories. Higher levels build upon more basic ones: a learner must *remember* (lvl-1) basic concepts in order to *understand* (lvl-2) them and organise them into a coherent framework. This makes it possible to *apply* (lvl-3) that knowledge to execute tasks in new situations. This enables the possibility to *analyse* (lvl-4) what was done and then *evaluate* (lvl-5) it, as the critical judgement of the outcomes is the key to *create* (lvl-6) new knowledge. The achievement of updated ILOs in a digitalised environment requires addressing the change of scenario and the relationship with the learner. A student-centred approach provides opportunities to learn, regardless of a student's learning profile (SLP) [3]. Whether they are Activists (they learn by doing); Reflectors (they elaborate on observations); Theorists (they abstract and create models to learn) or Pragmatists (they experiment), the educational methods and tools the educator

will implement should enable them the opportunity to learn in the easiest way possible and let them familiarise with different learning styles. The Kolb's Cycle [4] appears to be one of the pedagogical approaches that are well suited to answer this request for student-centred learning. For these reasons, the table containing a list of educational items (tools, methods and approaches) already maps them to the stages of the Kolb's Cycle, suggesting how/where to use them in physical and/or remote settings and in which kind of educational activity (lecture, seminar, lab, etc.).

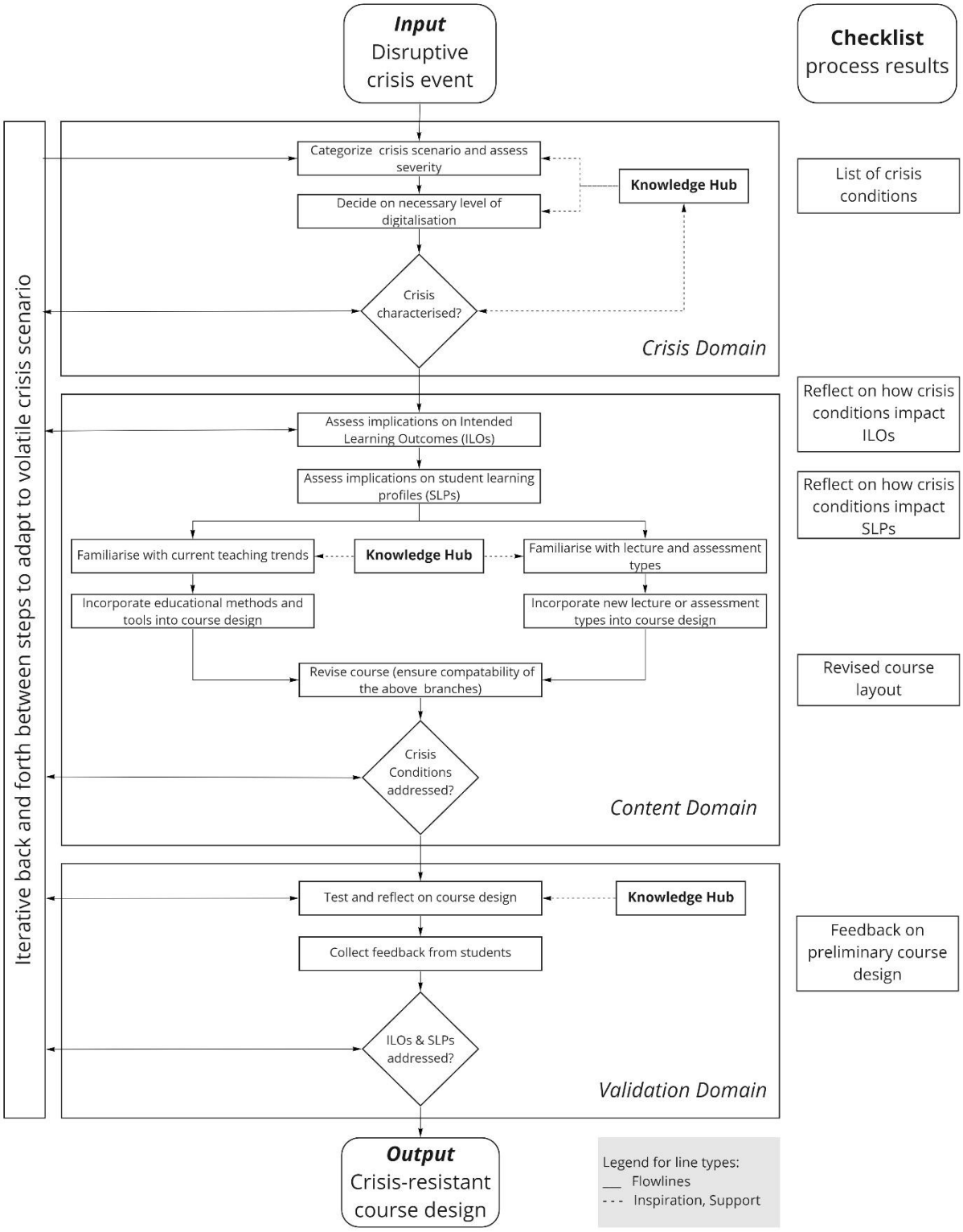

Figure 1. Depiction of the crisis-adaptation framework

2.3 Framework logical structure

Figure 1 depicts the framework within three major domains. The *crisis domain* composes of processes to identify and characterise crisis-related restrictions and to decide on the necessary level of digitalisation for the situation. To facilitate this, the list of generic crisis conditions provides guidance through the processes (Section 2.1). The Knowledge Hub is a planned platform that provides experience reports on how other educators adapted to crises, which should aid an applicant in classifying the event. A first decision gate ensures the quality of the outcomes from the first domain. Within the *content domain*, implications from previously defined crisis conditions on intended learning outcomes and student learning profiles should be considered. From these considerations and by consulting the review on modern educational goals (Section 2.2), the educator has to revise their course and integrate the situation-appropriate tools and methodologies into their revised course. The Knowledge Hub can present examples of revised courses and teaching practices from other educators. The second decision gate should ensure the proper fitting of adaptations in the revised course layout with crisis conditions. Assuming the implementation of the revised course, the applicant progresses to the *validation domain*. When testing the revised course layout in the crisis setting, the educator has to carefully monitor whether set learning outcomes are met and if student learning styles are addressed. This can be achieved by feedback from the students and a comparison of course layouts regarding irregularities in student behaviour and grading. The Knowledge Hub should again serve as a resource on how other educators experience a crisis and which problems were encountered during the implementation of their courses. A final decision gate provides necessary iterations for a complete *validation domain*. Determining a course layout is an iterative process, especially given the volatile setting of a crisis, which is indicated by the leftmost process (Figure 1) that enables the iterative back and forth between processes. To the right of the three domains (Figure 1), a checklist of process results can be found. It summarises activities within the domains and should facilitate the application of the framework.

3 VALIDATION - EXAMPLE OF FRAMEWORK APPLICATION

As a case example for the purpose of demonstrating how to apply the framework, an illustrative CAD course in the restricted scenario of a pandemic crisis is considered. Firstly, the addressed crisis situation has to be described with the list of crisis conditions (Table 1).

Table 1. Exemplary list of crisis conditions

General Conditions			**Level of digitalisation**
Movement	Geographic limitations	Severe restrictions due to lockdowns that prohibit all non-essential movement.	Completely Online
	Requirement-based limitations	Despite constantly changing requirements, it is generally enough to wear a mask and have a negative COVID test.	Physical, Hybrid, Completely Online
Connectivity	Internet connection	There are no problems with the internet connection.	Physical, Hybrid, Completely Online
Higher Education-Related Conditions			
Institution	Physical access	The institution and its resources are only partly accessible physically. Only essential personnel are allowed on campus.	Completely Online
	Online access	There are no limitations regarding the access to online services of the institution.	Physical, Hybrid, Completely Online
Learning resources	Online availability	There are insufficient online learning resources existent to support teaching activities. Educators need to create the missing online learning resources.	Physical, Hybrid, Completely Online

	Physical access	The learning resources are not accessible physically.	Completely Online
Personnel	Availability	Educators are fully available in general but can become unavailable once they contract the disease.	Physical, Hybrid, Completely Online
Personal Conditions			
Equipment	Availability	The equipment required for educational activities is partly available.	Physical, Hybrid, Completely Online
	Suitability	The available equipment is only partly suited for the intended educational activities.	Physical, Hybrid, Completely Online

Prior to the crisis, the example course consists of theoretical lectures that are carried out in an ex-cathedra format and tutorials supported by CAD tools. During practice exercises, students mimic the demonstration of CAD modelling by observing the lecturer's computer screen. Teaching assistants offer individual help during the exercises. The practical aspect of the course also comprehends a collaborative assignment, tasking students to develop a design solution to a real industrial problem. Students can ask for feedback or clarification during weekly consultation hours, whereby some meetings are compulsory. Grading consists of an individual test where students have to create 3D parts, an assembly, run simulations and create 2D drafts for documentation, in addition to an evaluation of the collaborative assignment. For the group evaluation, students present collaborative assignment results and prepare a report. All activities are carried out on-site. The intended learning outcomes of this course are to be able to create 3D models of parts and assemblies; prepare 2D technical drafts; conduct static, kinematic or dynamic simulations; and to ideate simple virtual prototypes.
In this case-study scenario, all course activities take place on-site. The condition "physical access to the institution" demands that students are not allowed on campus. A complete shift to online teaching is therefore recommended, affecting lectures, practice exercises, the student team assignment, consultation hours and examination. To achieve intended learning outcomes and satisfy student learning profiles, the applicant of the framework can incorporate methods and tools from the table of educational items. The process shall be demonstrated for lectures:

Table 2. Excerpt of the educational items table - Lecture type applicability

Educational Item	**Applicable to Lecture type**					
	Lectures	Exercises	Seminars	Projects	Laboratories	Excursions
Physical Prototypes	X	X	X	X	X	X
Gallery Method	X	X	X	X		
Classroom discussion	X	X	X	X	X	
AR-Visualisation	X	X	X	X	X	X

Table 3. Excerpt of the educational items table - Learning style applicability

Educational Item	**Applicable to Learning style (Kolb's Cycle)**			
	Concrete Experience	Reflective Observation	Abstract Conceptualisation	Active Experimentation
Physical Prototypes	X	X		X
Gallery Method	X	X	X	X
Classroom discussion		X	X	X
AR-Visualisation	X	X	X	X

Ex-cathedra lectures can be held online via videoconferencing tools or be supplemented with recorded lectures and live meetings to discuss the contents of the recording in a flipped classroom format. Lectures can be enriched with educational items such as physical prototypes, the gallery method, and augmented reality visualisation to address the concrete-experience learning style. Classroom discussions facilitate students with an active experimentation learning profile. Tables 2 and 3 depict educational

items from the table and suggestions for practical implementation. Once the educator has implemented the course revision, student feedback and before/after comparison of the courses are needed. Through feedback, the educator can either verify course adaptations or reiterate the process.

4 DISCUSSIONS

The need for this type of research became visible during the COVID-19 crisis in the spring of 2020. Successive infectious waves for the past two years have shown that new rapid and region-specific adaptations will be again needed and experienced in the everyday and professional life of educators and students. To address this and other present and future crisis events, the paper presents a framework for the rapid adaptation of engineering product development courses. The example of the framework application demonstrates how educators in higher education can use the presented resources. Resources include the crisis conditions list to identify restrictions and to assist in determining the appropriate level of digitalisation, and the modern teaching objectives review in conjunction with the educational items table to enhance their courses with previously assessed methods and tools. The practice-oriented, crisis-resistant guidelines provide educators with a structured and tested approach for reacting to a crisis and adapting their course in alignment with the framework. This will not only lighten the burden on educators but also addresses the need for fast decision-making in a volatile environment. The goal from an educator's perspective has to be to maintain an excellent knowledge transfer and to keep all types of learners engaged in teaching activities.

The framework is currently being validated in product development courses conducted by the authors. It is the ambition of the authors to create a comprehensive platform for educators to exchange experiences from past and present crisis events, called the Knowledge Hub, and make the framework accessible in an interactive online form.

ONLINE APPENDIX

Please refer to our website www.cresdet.eu/framework/ to find the resources of the framework: Generic Crisis Conditions List, Review of Educational Objectives, Educational Items Table

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