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A learning design framework based on UDL principles to develop maker projects for pre-service teacher and educator training

Un framework per il Learning Design basato sui principi dell'UDL per sviluppare progetti maker per la formazione di futuri insegnanti ed educatori

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Abstract. During pre-service teacher and educator training it is essential that future teachers and educators learn how to design a learning module or a curriculum and that they master an approach of learning design, considering also inclusion and equity issues to increase participation and learning of all the students, embracing their diversities and addressing their different needs. The aim of this study is to describe an encompassing approach of learning design infused of Universal Design for Learning (UDL) that was developed and adopted within a Faculty's Laboratory on educational technology targeted at future primary school teachers and within a Course on Maker Education for the future educators of the Degree Course in Education. This Framework is the result of the experimentation of various previous versions of it during the last two academic years and appears to promote the creation of accessible, engaging and inclusive maker education projects that meet the needs of each learner.

Keywords: learning design, universal design for learning, maker education.

Riassunto. Nella formazione dei futuri insegnanti ed educatori, è essenziale che essi imparino a progettare un modulo didattico o un curriculum e che padroneggino il learning design, considerando anche le questioni relative all'inclusione e all'equità per aumentare la partecipazione e l'apprendimento di tutti gli studenti, accogliendo le loro diversità e rispondendo alle loro diverse esigenze. Lo scopo di questo studio è presentare un approccio onnicomprensivo al learning design, ispirato all'Universal Design for Learning (UDL), che è stato sviluppato e adottato all'interno di un laboratorio universitario sulle tecnologie educative rivolto ai futuri insegnanti della scuola primaria e all'interno di un corso su Maker Education per i futuri educatori del Corso di Laurea in Educazione. Questo framework è il risultato della sperimentazione di varie versioni precedenti, che sono state realizzate durante gli ultimi due anni accademici; esso sembra promuovere la creazione di progetti di maker education accessibili, coinvolgenti e inclusive, in grado di soddisfare le esigenze di ogni discente.

Parole chiave: learning design, universal design for learning, maker education.

1. INTRODUCTION

During pre-service teacher education it is essential that future teachers and educators learn how to design an innovative learning module or project and that they master novel approaches of learning design, considering also inclusion and equity issues. As a matter of fact, universities in charge of pre-service teacher and educator training should prepare future teachers to be able to design digital inclusive teaching to increase participation and learning of all the students.

To this end, maker education can offer significant opportunities to students in conditions of social, economic and cultural disadvantage or with learning difficulties (Leonard et al., 2022). Maker education is a cultural movement that is spreading in the educational field and is focused on the innovative use of digital tools, which combines creative approaches to scientific activities inspired by industrial design and engineering.

According to one of the proponents of this movement, Blikstein (2013), the processes of ideation, design and implementation inherent in this approach can be traced to the key concepts of Papertian constructionism (Papert, 1993) and have their roots in pedagogical activism of Dewey and Montessori. In fact, as makers, learners actively and experientially build their knowledge through hands-on activities that combine manual skills with the exercise of digital competencies, aimed at solving open problems inspired by daily life through creation of physical and digital artifacts. Maker Education identifies in STEM the main vector for spreading in schools by integrating with traditional disciplines. The activities focused on Maker Education include coding, robotics, circuit making or 3D printing.

The way in which the maker movement as well as the concept of equity are conceived can affect the potential that this movement can confer on educational experiences aimed at students most at risk (Voussoughi et al., 2016; Hsu et al., 2017; Campos et al., 2019; Yao et al., 2020). Students and young people who already possess know-how or who are more inclined to participate in maker activities as they are more interested in science subjects, have greater learning opportunities than others, who end up being excluded from these experiences, or to exclude themselves. Nevertheless, even those groups of children and young people most at risk and who historically do not have equal access to disciplines pertaining to STEM, could provide an innovative contribution to these activities, drawing on their own interests, cultural practices and on those of communities to which they belong (Barton and Tan, 2019; Repetto 2020; Leonard et al., 2022).

The use of maker technologies associated with new ways of dealing with interdisciplinary topics, promotes what Vossoughi et al. (2016) define an epistemological pluralism. Mathematic concepts or physical phenomena, for example, can be explored through the construction of physical and digital objects, with such flexibility as to allow students, in the role of scientists, artists or designers, to express themselves driven by their own curiosity. At the same time, the activity does not leave the initiative entirely to the student, such as it happens in pure discovery learning (Wong et al., 2010), but it is structured so that the support of the teacher or expert maker acts as scaffolding for the development and testing of specific ideas.

Thus, designing a project or a lesson plan for maker education in an essential competence for teachers, educators and maker experts, requiring systematic training that begins during higher education (Wu et al., 2021). According to social constructivism, this kind of training should be competence-oriented, student-centered and technology-enhanced.

In this sense, learning design approaches can support teachers to develop dynamic educational projects whose focus is on learners, that are inspired by constructivism and whose activities are situated within authentic learning contexts (Repetto, 2021). Among the various learning design approaches investigated through a literature review performed througj design-based research (DBR), design thinking was considered the most suitable one for maker education (Panke, 2019): the nature of design thinking activities, mainly based on hands-on experiences, is similar to those of makers, as well the mindset inspiring the activities; moreover, the focus on a problem that is the starting point of each maker project, is the first step for design thinking process as well.

In the present study an encompassing approach of learning design based on design thinking and infused of Universal Design for Learning (UDL) and the process leading to its development are described, with the aim of contributing to our understanding on how to foster the development of maker learning design expertise. This model of learning design, for whose development the adopted research methodoloy is Design-Based Research

(DBR), was experimented within a Faculty's Laboratory on computational thinking targeted at future primary school teachers and within a Course on Maker Education for the future educators and learning experts of the Degree Course in Education.

This contribution is divided into two parts: in the former, two distinct approaches for maker education (Design Thinking and UDL), are described. In the latter, a learning design framework for the development of maker project is presented, deriving from the combination of the approaches described in the first part.

2. DESIGN THINKING AS A LEARNING DESIGN APPROACH FOR MAKER EDUCATION

Design thinking can be considered as the main approach to design projects, modules and activities based on Maker Education. This approach promotes innovation through creation of ideas and their realization that takes into account the needs of target users. This approach was created by the Stanford Design School (Dell'Era et al., 2020) and thus was generated outside of the educational field and applied mainly in economic and industrial contexts. Nevertheless, being a human-centric process and fostering creative problem solving, it appears as perfectly reconcilable with some pedagogical prerogatives of the constructionist paradigm and of the activism of maker education, such as learner-centeredness, inquiry-based learning and experiential learning.

The Design Thinking approach fosters innovation and creativity through its main five phases (Figure 1):

- Empathize: learners identify a complex problem and start enquiries in order to collect as much information and knowledge as possible in relation to the problem to be solved. This phase is carried out by learners through an ethnographic methodology in order to better define the final audience they are designing for and to understand their experiences and motivations, during which learners gain a deeper understanding of the problem.
- Define: after that data have been collected, during this phase learners tackle the identified problem discussing and providing a clear definition of the core issues of it.

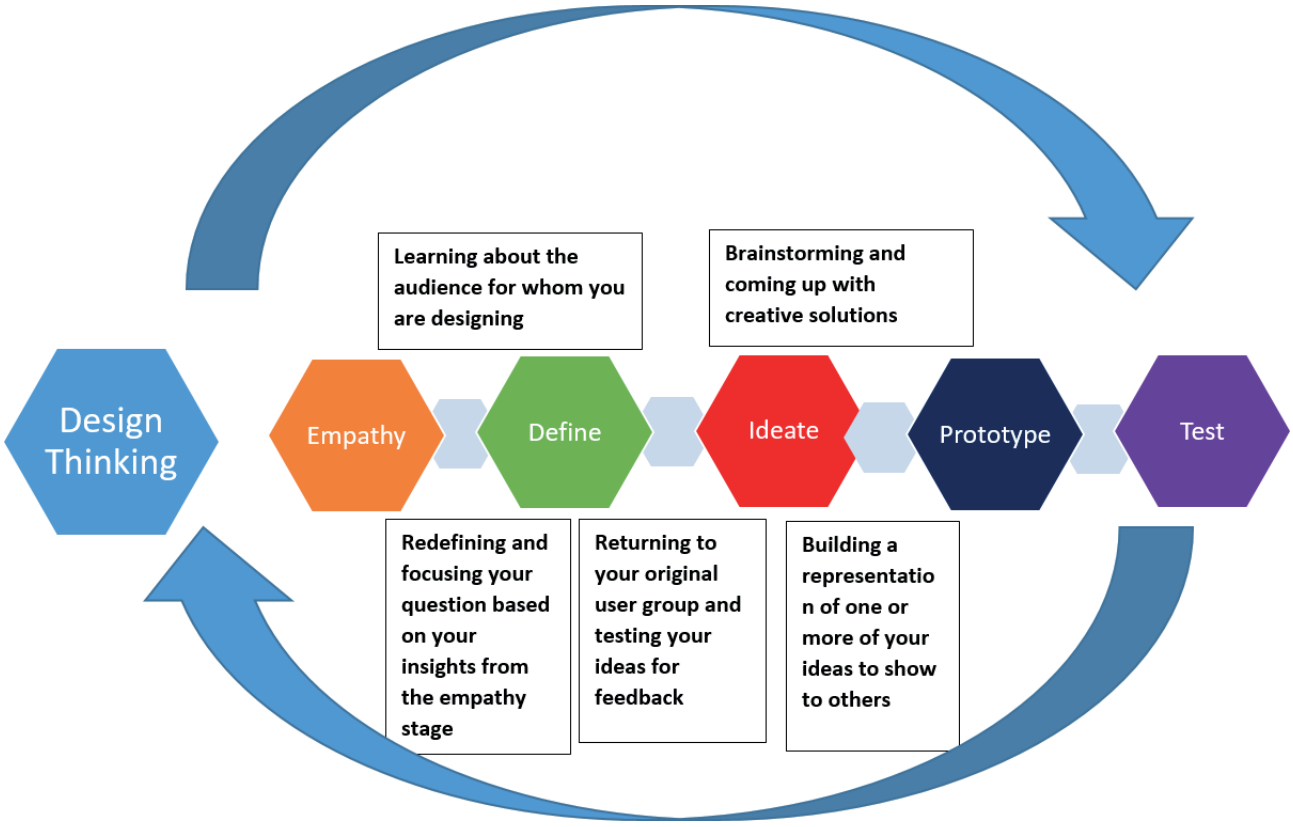

Figure 1. The Design Thinking process used by the learner to solve a design challenge (MrJanzen1984, Creative Commons CC-BY-SA-4.0).

- Ideate: it's the time when there are no prejudices and each learner of the team freely expresses her suggestions and generate ideas, which will be then selected to collect what they deem to be effective and innovative for solving the problem.
- Prototype: it is the time of concrete realization of the project and in which the idea takes on a shape through the development of a prototype, being careful of the identified problems and of possible improvements. At this stage there is a very intense reflection and discussion in the work team, during which solutions may iteratively lead to failure and the team learns from it and from feedback.
- Test: the project is finished and improved, and ready to be delivered to the final audience from which learner receive further feedback to refine their solutions.

Design Thinking is pervasive thanks to its applicability throughout all the subjects and across them; it's based on project-based and on hands-on learning activities that connect scholastic knowledge with authentic problems outside the school. The design process is not linear but is iterative in each phase: to skip backwards in the process and to make several revisions of a solution has an educational value for learners. In this sense, the concepts of iteration and risk-taking take on a strong relevance to support the learning process (Hsu et al., 2017) and make Design Thinking perfectly fit with Maker Education.

The frustration resulting from having made a mistake is essential to activate that recursive feedback process characterizing maker activities and leading to the solution of the problem. By solving authentic problems, which refer to their daily life, students learn, develop new skills and create new meanings (Vuorikari et al., 2019).

The iteration is understood in an even broader sense by Barton and Tan (2018; 2019), who attribute to this element a crucial role, not only in supporting the learning process in maker activities, but also in challenging traditional visions of knowledge creation. In fact, taking into consideration the cultural aspects of the students' community in order to be able to continuously and recursively inform the decisions concerning the planning of maker initiatives, more inclusive and culturally sustainable practices can be adopted.

Therefore, iteration is not limited to the recursive cycle of making, prototyping and testing necessary for the construction of artifacts and for the solution of problems, but also concerns the iterative and expansive cycles necessary to take into consideration the socio-cultural context of the students. Thanks to Design Thinking, maker environments or maker educational initiatives can then be created in areas at risk of marginalization involving the community itself (Repetto, 2020; Leonard et al., 2022), in addition to the students who may also be part of it, in the planning of activities and in the management of the environments themselves. Thus, both learners and audiences of a community are stimulated to imagine and implement new forms of active citizenship, that can contribute to create a new collective identity and to emancipate themselves from the label that place that community on the margins.

For all the reasons listed above, Design Thinking appears certainly one of the most relevant approaches for the design of maker education initiatives, that could represent a learning design approach on which preservice teacher training should be focused to empower future teachers and educators as innovative learning designers. Moreover, training on this approach, as well as on other methods of human-centred design, help teachers to adopt a design mindset and to develop the skills necessary to address the design challenges they meet in everyday educational life (Garreta-Domingo et al., 2018; Persico et al., 2018).

Nevertheless, Design Thinking needs also to be pedagogically founded in order to maximize the impact of this approach on learning processes and to make these processes effective for all the students, independently from their subjective difficulties and from the disadvantageous situations that are experiencing. Thus, Universal Design for Learning (UDL) and its three underpinning principles applicable to education for a fully inclusive approach could be taken into consideration for the design of maker education initiatives.

3. UDL AS AN INCLUSIVE APPROACH FOR MAKER EDUCATION

It is essential that the teacher's approach is engaging and considers the various ways in which knowledge is achieved. Universal Design for Learning (UDL) offers the possibility of developing educational activities using multimodal strategies. The term UDL was used for the first time in 1995 by CAST (Center for Applied Special Technology) (2021). This term derives from Universal Design, which aims at creating an architectural product that should always consider the differences between users.

The purpose of UDL is to provide multiple modes of activity on a topic, to promote different forms of learning for all students. This purpose is based on the fundamental principle that, a key element of learning, is not only that of transmitting information, but also that of encouraging each student to build their own knowledge,

which can only take place if the topics and activities presented are accessible to all.

UDL is grounded in recent advances of the cognitive neurosciences (Rose & Strangman, 2007). Our brain, plastic and flexible, perceives the information that arrive through the senses in the recognition networks, which are located in the back in the temporal and occipital lobes; here the data are processed and sent to the center of the brain in the form of meanings in the affective networks, to be then organized as responses or actions in the frontal lobes, headquarters of the strategic networks. The brain is not only plastic, it is also different in each person. This awareness makes us understand how important it is, for a teacher and an educator, to consider the fact that each individual has a personal or preferred learning strategy, which is based on the different parts of the brain that work together in a synergistic and complementary way, as well as on the type of environmental context in which it is located. There is no one-size-fits-all way in which the brain perceives and performs the tasks that lead to learning. There is a variety among students learning and also for the same student who learns differently in different contexts.

UDL is a design methodology based on three fundamental didactic principles (Hall et al., 2012) deriving from the above mentioned neurocognitive theory:

- to provide multiple forms of representation of the contents, connected to the recognition networks, the what of learning (What);
- to provide multiple forms of action and expression, connected to strategic learning networks, the how of learning (How);
- to provide multiple forms of involvement connected to affective networks, the why of learning (Why).

The principle of what (García-Campos et al., 2020) takes into consideration that students, in relation to their own characteristics, differ from each other in the way they perceive and understand the information presented to them. Each student brings with him a unique set of knowledge and personal experiences and the educational curriculum must be highly flexible to accommodate the various ways of accessing the content by a plurality of students. For example, different physical or learning disabilities, linguistic or cultural differences require different ways of approaching content such as written text, visual representation or oral narration. The use of multiple representations of the same content allows students to make connections between what they have already learned and the content they are experiencing, making knowledge truly accessible to everyone (Vie, 2018).

The how principle arises from the awareness that students differ in the ways in which they personalize their learning paths. The action and expression of what has been learned requires a large number of strategies and practical organization; thus, it becomes essential to provide students with a range of tools to use different possibilities of expression to demonstrate what they have learned.

The why principle highlights how awareness of the motivational aspect allows us to positively influence the learning process. In fact, there is no equal motivation mode for all students and it is therefore advisable to provide different options of involvement in school work, which can reflect the different needs of students.

These three fundamental principles are divided into guidelines, check lists and operational controls, which allow to prepare a flexible planning with methods, objectives and tools that take into account the diversity in the learning methods of all students. The application of these three principles is carried out throught a critical selection of technologies and learning strategies that allow students to benefit from alternative tools to the classic written text, favoring, for example, technology-enhanced learning; it is not the content that is innovative in itself, but rather the means of presenting it; moreover, thanks to technological-enhanced strategies, content becomes dynamic and transformable.

4. METHODOLOGICAL DESIGN

Design Thinking and UDL were experimented in this study as a reference framework for scaffolding among university students the design of digital learning activities and projects for maker education. Both these approaches stimulate innovative learning practices for student-centered design.

Many scholars argue that the application of UDL principles to learning design process facilitate the design of inclusive activities that address the needs of all the students (Dell et al., 2015; Elias, 2010), who are different under multiple and overlapping dimensions (Sanger, 2020). Thus, in the context of this study, UDL was applied for the development of a learning design approach that was experimented in one of the faculty laboratories of educational technology for future primary school teachers, in which ICT training is carried out according to the TPCK model (Bruschi, 2017). Moreover, the same learning design model was experimented in a course on maker education of the Degree Course in Education.

This study has used Design-Based Research (DBR) (Anderson and Shattuck, 2012) methodological approach, that combines a theory-driven approach with empirical evaluation. DBR was used to build the learning design model presented in this study, which

Figure 2. The design-based research approach adopted in the study.

was developed through the four iterative phases underpinning the approach recommended by Reeves (2006), that were adapted for this study: analysis of problems by researchers and pratictioners (HE students), development of prototype solutions of learning design pattern and approaches, interative cycles of testing of learning design approaches and reflection aimed at refine the last version of learning design approach (Figure 2).

The participants of this study were two cohorts of third-year undergraduate students of Primary Education Science (N = 105) and three cohorts of third-year undergraduate students of Educational Science of the branch "Experts in learning processes and languages" (N = 45). The courses were respectively the "Lab on Educational Technology" and the course of "2D and 3D Technologies for Learning", that took place in the period between fall semester 2019 and spring semester 2021.

In the following sub-paragraph details on the four phases of research are provided, that were iteratively replicated in each academic semester, for a total of four-round design-based research process.

4.1 Analysis of LD approaches

During this phase, an extensive literature review on learning design approaches and on maker education was performed to identify and narrow down the problem that, as anticipated in the introduction, concerns the necessity to train future teachers and educators on innovative and inclusive approaches to design learning projects during pre-service teacher education. This phase was iteratively replicated after each round of the design-based research process, taking into account the findings of the DBR fourth phase on reflection.

This exploration helped to comprehend all aspects of the identified problem and provided also an understanding of the research context, of the objectives to be achieved and of the strategies to adopt in the subsequent phase. The exploration of scholarhip on learning design approaches, has allowed to identify the most important ones. Learning design approaches such as R2D2 (Willis, 1995), LAMS (Dalziel, 2015), Learning Designer (Laurillard et al., 2018), or OULDI (Conole, 2012) share some essential characteristics: these are inspired by a constructivist matrix, their teaching approach values learning in meaningful contexts and teachers as well students have a pivotal role in the whole design process. The iterative application of DBR has allowed to progressively refine the selection of these learning design approaches to identify design thinking as the most relevant for the specific context of maker education. Design thinking became the starting point to develop and experiment an effective learning design approach: a comparative review of existing design thinking approaches was performed to develop an approach able to connect all the positive aspects springing from them.

4.2 Development of approaches to LD

During the second phase of the design-based process, various solutions to solve the problem identified in the previous phase – to obtain an effective design approach for maker projects - were ideated, involving also the undergraduate students during learning activities. The ideation of a feasible learning design approach for maker education was carried out also creating planning grids and design outlines and schemes starting from previous attempts of other researchers in this field.

Kilpatrick et al. (2021), for instance, promote the development of a UDL mindset among teachers and educators, that should be fused with design thinking. The structure of their model appears to be a feasible solution for the connection of Design Thinking with UDL and the various phases of Design Thinking are iteratively replicated for continual improvement. Nevertheless, how to integrate each principle of UDL in the various phases of Design Thinking is not specified and projects developed by students according to this approach were rather incomplete.

The learning design approach by Gerstein and Bray (2017) instead, provides a structure that integrates Design Thinking with UDL, accompanied with examples of grids that can be used also to design maker educational projects. Nevertheless, in this approach the Design Thinking process includes also further three phases that make it more complex and detailed. Some examples are provided by the researchers on how to apply UDL in each of the nine stages, but not all the

three UDL principles are explicitated. Moreover, the high number of stages constrains designers to follow that structure with the risk of dampening their creativity. The projects developed by students who embraced this approach were too similar to each other.

The adopted design approaches that were ideated during this phase were iteratively experimented in the subsequent phase of testing.

4.3 Testing of approaches to LD

The limits of each learning design approach and of each solution ideated in the previous phase were identified during the testing stage, occurring during the various editions of university labs and courses. One of the learning units of these courses was centred on the development of a project of maker education that students performed in groups. Each group was in charge of adopting the learning design approach selected by the teacher that should be tested in that edition. Each group had at its disposal a series of learning resources such as articles, planning grids and design outlines that students should discuss and eventually modify according to their needs and on the basis of the context in which they were willing to situate the maker project. The aim of each project was to develop a project adopting a design thinking approach, trying to integrate UDL principles and strategies in each stage of the process. The students, in addition to the project developed for specific target audiences and on a topic or problem identified by them, were in charge of developing a prototype and documenting the whole design process producing an updated and contextualized version of the grids and design outlines provided by the teacher. As can be seen in the examples of Figure 3, students produced several and original types of schemes for their project, receiving a scaffolding during the design process and a formative assessment at the end of it.

4.4 Reflection on a LD approach

The projects developed by the groups in the third phase of testing were object of discussion among them and with the teacher, who was in charge of evaluating them and to select those design schemes and pedagogical patterns that appeared to be more effective, innovative and of an higher quality. A relevant further criterion to select them was their applicability in a real context.

At the end of this fourth phase of reflection, which marks the end of a round, other three rounds took place involving the same four stages, one round for each edition of the courses involved in the study. The aim of each round was to progressively improve and refine the

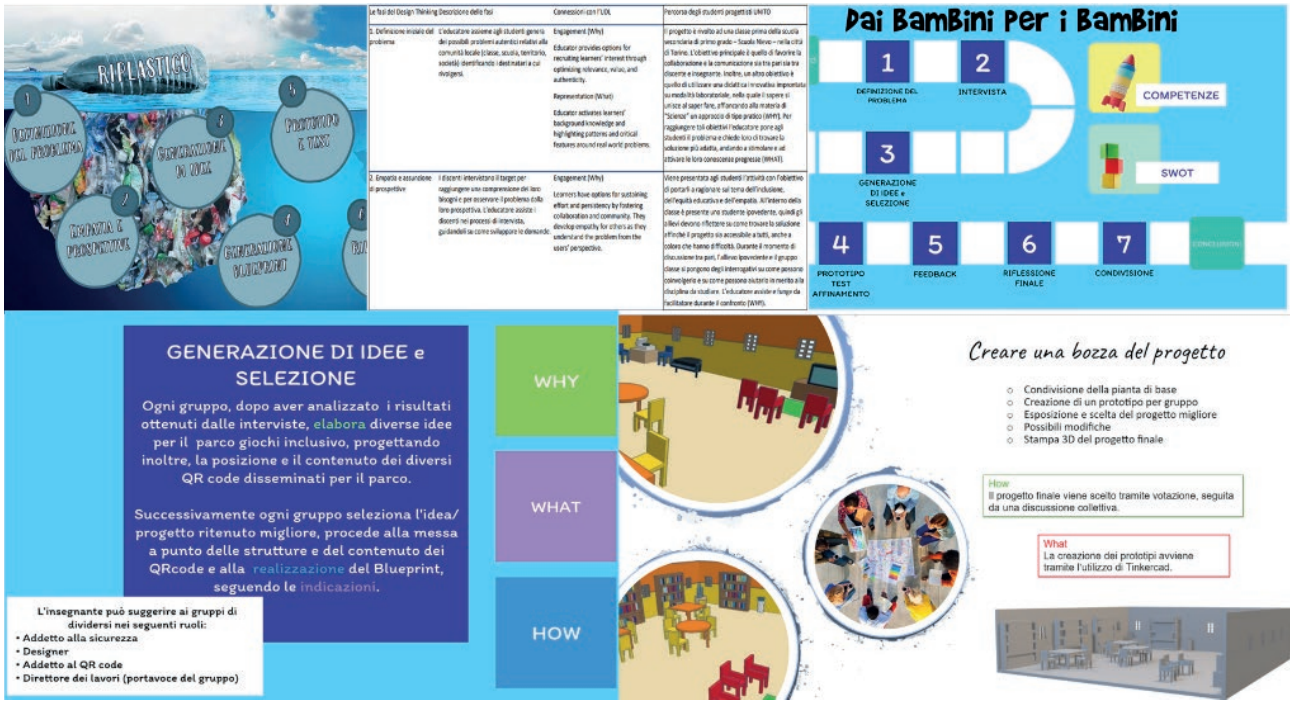

Figure 3. Instances of structures and pedagogical patterns developed by university students.

obtained findings, revising literature, developing new learning design solutions, testing them and refining the final learning design approach.

5. A FRAMEWORK FOR THE LEARNING DESIGN OF INCLUSIVE MAKER PROJECTS

As described in the previous paragraph, each subsequent edition of university courses and labs were the context of this study and focused on the design of maker education projects, with a total of 30 projects designed in two years. Starting from the analysis of efficacy and relevance of these projects designed by students, each edition saw the iterative development and refinement of a learning design approach infused by UDL, which future teachers and educators may use as a framework to develop their own inclusive maker projects when they will be practicing teachers or educators.

This framework (see Figure 4) was progressively improved and refined to obtain a tool that scaffolds the design of projects on maker education. It uses as the primary basis and as the main background the Design Thinking classical model with its five phases. For each of these phases, the three main priciples of UDL are applied whose focus is, as described in Par.3, providing multiple means of representation, of expression and engagement.

The guidelines accompanying these structure helps to take into account all the main aspects of teaching and learning processes: learning goals, delivery methods, physical and virtual spaces, learning resources and activities, technology, learning strategies and the assessment approach. At the same time, these guidelines explain each phase of Design Thinking and in which ways the three principles of UDL should be integrated in that stage. Each phase could comprehend one or more learning activities, but each activity should contain in itself all the necessary elements that meet the three UDL principles. The Empathize phase, for instance, could envisage more than an activity: an introduction to the general theme of the project and an enquiry targeted at final users of the educational project. For the introduction to the general theme, university students should design an activity taking into account the three UDL principles:

- students who are the target of the project should be motivated involving them in enquiries on the general theme that could be carried out choosing if working alone or in group (the why of learning);
- teacher could provide multiple resources (articles, videos, conceptual maps) to represent knowledge needed by students to frame the problem (the what of learning);
- students could demonstrate the knowledge acquired through the production of individual or collaborative contributions choosing their preferred format (the how of learning).

The next four activities (define, ideate, prototype and test) are structured in the same manner, to ensure that it is inclusive enough to meet the needs and the interests of each student.

6. CONCLUSION

The framework developed in this study provides future teachers and educstors with guidance needed to address complex problems concerning maker education, while enhancing their learning design compentencies.

The Design Thinking model included in this framework emphasizes the human-centred perspective throughout the design lifecycle and provides an approach focused on practice (2018). In addition, UDL represents in this framework an essential tool, indicating in which ways each activity and each phase of the Design Think-

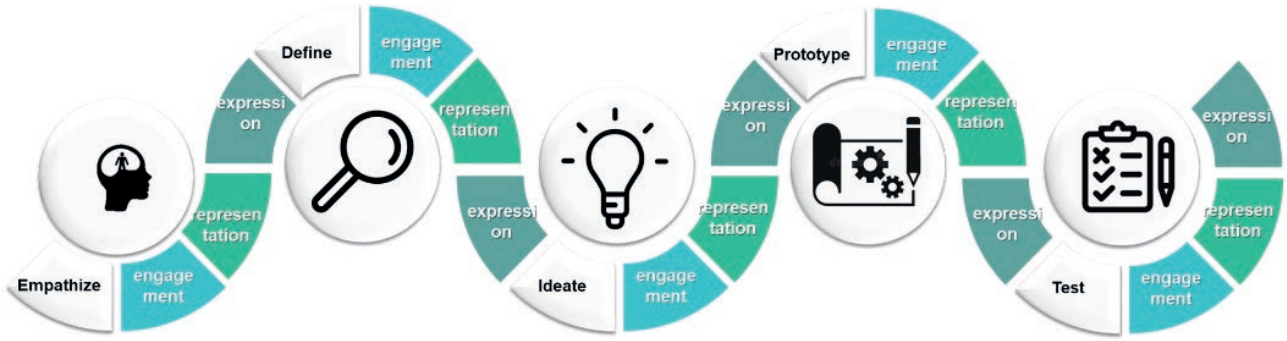

Figure 4. The structure of the framework to design inclusive maker education initiatives.

ing approach can become an inclusive activity for students with an educational value and a direct connection with the relative learning objective. This framework should promote the creation of accessible and engaging digital curricula that meet the needs of each learner; moreover, it should support the design of technology-enhanced learning environments and of digital tools for inclusive teaching design (Armstrong et al., 2018).

Some possible directions for further research include the development of a digital version of this framework to make more agile for university students the design of inclusive maker projects and a comparative study of projects that teachers and educators will implement according to this approach after graduating.

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