Six-year evolution of a space-inspired collaborative problem-solving study program in Finland

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Abstract

This paper presents the results of the six-year qualitative longitudinal case-study of the Epic Challenge study program in Finland. Created in 2008 for NASA engineers, the Epic Challenge program has grown and evolved to teach collaborative problem solving that reaches across different disciplines and ages. The paper presents an overview and evolution of program features and teaching methodologies. In the program, students learn a challenge-based methodology called Innovative Conceptual Engineering Design (ICED) and use this methodology to develop innovative solutions connected to the overarching challenge of sustainable human habitation of Mars. The program is built around the assumption that space exploration as a complex, multidisciplinary challenge provides the inspiration, a driving force and integrated curriculum for teaching Science, Technology, Engineering and Math (STEM) concepts and problem-solving techniques in four key areas: teamworking, networking, systems thinking and innovation. In 2015 the program was adopted and fused with a phenomenon-based learning curriculum in Finland, and it grew to be taught to students of various backgrounds from high-school to doctoral level. The course delivery and content were modified annually based on lessons learned and more than 500 students have gone through the program in Finland. The paper presents the evolution of key program features and concludes by presenting the most robust features of the program implementations that could benefit space agencies, companies and faculty interested in promoting space and STEM related competences.

Keywords

challenge-based learning, collaborative problem solving, innovation education, STEM

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Acronyms/Abbreviations

ICED	*Innovative Conceptual Engineering Design*
STEM	*Science, Technology, Engineering and Math*
ECP	*Epic Challenge Program*

1. Introduction

Epic challenges are problems that are very complex by nature due to many interacting elements within and to be solved they require expertise from many fields. Due to their importance, urgency, and complexity they become a motivational force for large audiences. In this paper we present an educational program that shows success in passing skills and attitudes that are needed for solving such challenges. Moreover, it seems to encourage younger students to study STEM subjects and pursue careers in Science, Technology, Engineering and Math (STEM) [1] and entrepreneurship [2]. Space as an extreme and still to be discovered environment has been the driver of the program as a great source of highly complex, unsolved challenges.

Problem-based and collaborative learning have been shown to promote skills (negotiation, organization, leadership, teamwork, communication etc.) needed for twenty-first century workers in STEM areas [3]. As these teaching strategies are problem-oriented rather than subject oriented they encourage students to become active participants during the learning process as they are using knowledge rather than just recalling it [4,5]. It has also been defined that to manage change in the society and in the work life, new types of competencies, such as collaborative learning, self-leadership, and flexibility, are needed [6]. One example of a nationwide action to combine aspects of problem-based learning, explorative learning, and project-based learning can be seen in Finland where phenomenon-based learning has been introduced to the core national curriculum for basic education since 2016 [7].

The Epic Challenge Program (ECP) teaches team-based problem-solving skills in four key areas: teamworking, networking, systems thinking and innovation. In this paper we study the features of the program implementations in Finland and discuss the most robust features as the program expanded from being taught to NASA junior engineers to the general public. Section 2 introduces the origins of the ECP and its expansion in Finland. Section 3 introduces the methodology used in analysing the features of the program. Section 4 provides an overview of the program features. Section 5 offers explanation on why some features remained, evolved, or faded away. Section 6 concludes the paper with listing the most robust program features.

2. Epic Challenge Program

2.1. Origins of the program

The original idea for such a program occurred to astronaut Dr. Camarda in 2003 while training as a backup crewmember for an Expedition 8 mission to the International Space Station. During his training, the Space Shuttle Columbia and its crew were lost during entry from space. NASA struggled for the next 2.5 years trying to understand the “root” causes of the accident. During this time, it became apparent to Dr. Camarda that critical skills to develop innovative solutions to complex problems were sorely missing at the Johnson Space Center, where he was training as an Astronaut. He used his skills to help the center develop several teams to solve critical problems and to develop technologies needed prior to his launch on the return-to-flight mission, STS-114. He initiated and led a research team which verified the technical cause of the accident and accurately predicted impact damage to Orbiter vehicles and an R&D team which developed an on-orbit repair technique to fix a damaged wing leading edge in space. When returned from space he formalized his innovative engineering design strategy into a pedagogy called Innovative Conceptual Engineering Design (ICED) [8].

2.2. ICED Methodology

The ICED methodology is based on the creation of psychologically safe virtual and physical environments to solve real-world engineering problems. Throughout this process, students are encouraged to explore, experiment, fail, discover, and learn. The methodology draws upon the teaming of very diverse groups of students, engineers, scientists, designers, artists, etc. to explore an open-ended design space and exercise both hemispheres of their brain, the analytical left and creative right, to conceive and develop innovative solutions.

The ICED methodology was initially taught as a formal summer short course as part of the NASA Engineering and Safety Center Academy Program in July 2008 at Penn State University to instruct NASA engineers in the art and science of innovative engineering design [8]. A follow-on study, led by a small university student team, selected one of the concepts generated during the course and developed a solution to a problem NASA was struggling to solve for over 50-years, the safe land landing of a crewed space capsule [9]. This was proof that this challenge-based methodology would work both as a motivating force to attract and sustain student interest and as a mechanism to explore and rapidly mature innovative ideas.

The ECP was founded in 2010 and has attracted thousands of students in the United States to help solve challenges related to human spaceflight and the colonization of space. A 501(c)(3) educational nonprofit, the Epic Education Foundation [10], was formed to formalize the educational components and to run challenges for students around the world. Some of the results of early projects can be found in reference [1]. The program has grown to reach students in Finland and Australia and is planning to reach students in Mexico and Brazil this coming year.

2.3. Program expansion in Finland

EPC has been running in Finland since the 2015-16 school year [2,11]. Until now it has been implemented every school year and within each there were multiple iterations. Since the start the EPC has hosted over 500 participants from different study levels (doctoral, MSc, BSc, vocational college, and high school), from which over 35% identify as female. The participants represented over 15 different degree programs, from both natural and social sciences, and 17 different nationalities. Each program iteration allowed the local teachers to test and adjust different features of the program to suit these different backgrounds and levels of education. The participating teams, challenges they tackled and some of the solution they developed can be seen at the Finnish programs' website [11].

3. Research Methodology

Scientific knowledge evolves from early descriptive forms to practically useful prescriptive theories [12]. This current paper contributes to the field at the level of late-stage descriptive theory-building where relationships between different observable phenomena are defined. Specifically, different educational program features are rank-ordered based on their robustness. Here, robustness is defined in the most general way as the age of various program features still in use. Statistically, the expected lifetime of a non-perishable thing, such as a practice, is proportional to its age [13]. This principle is captured for example in the TRL classification, where highest readiness is assigned to technologies that have been used repeatedly in real missions [14]. In this paper, listed program features and their age are based on a past paper [2], existing documentation and the authors own personal memory of past implementations of the ECP.

4. Epic Challenge Program Features

The following section describes the key features of the program and how these features evolved over the six years. Figure 1 lists features in use by school year since 2015 until 2021.The blue line indicates when a feature was in use.

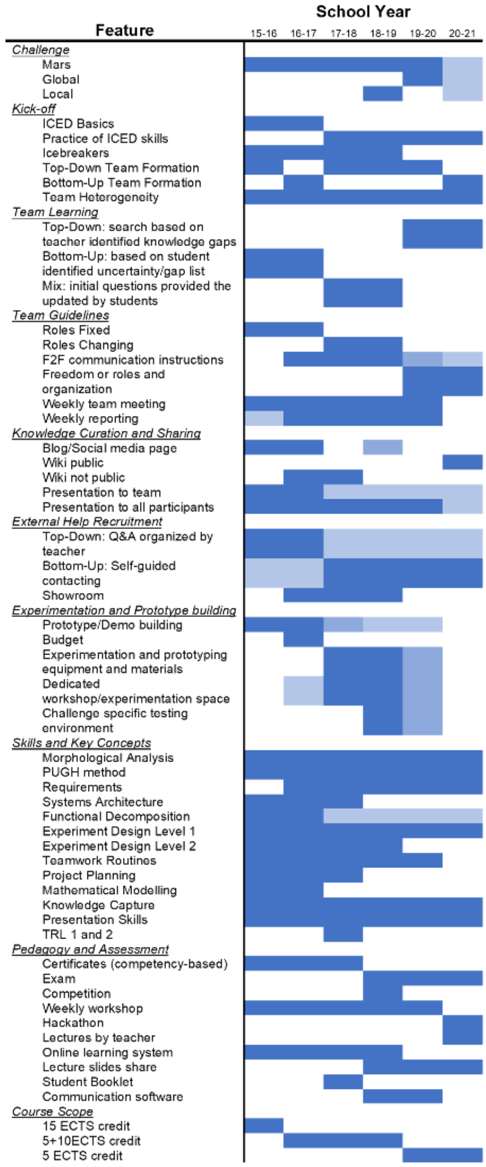

Figure 1. List of program features. The blue line indicates when a feature was used. The shading indicates degree of usage: dark blue = fully in use, medium blue = reduced usage, light blue = further reduced usage

Originally, ECP was a one-week intensive learning program [1]. In Finland it started as nine months long 15 ECTS credits course. Over the six years it evolved to fit the Finnish university course scope better. In the second year it was divided into a 5 ECTS introductory and 10 ECTS advanced course and in the third it was compressed so that the 5 ECTS course could be completed in one period (8 weeks) and the 10 ECTS course in two periods (16 weeks).

Every year a variety of ***challenges*** was offered for student teams to choose from. In addition to clarity and epicness, in the challenge definition, linkage to local R&D resources were considered. The methodology has been applied also to solving global challenges concerning Earth and local challenges relevant for the region. Some of these challenges had an analogous Mars-themed challenge.

The ***Kick-off Week*** is an introductory intensive week at the beginning of the program aiming at familiarization and team formation. The content of this week has evolved from introducing the methodology to practicing the skills and tools needed to implement the methodology to solve the challenge. ***Team Formation*** supporting activities such as icebreakers, introduction rounds, mingling exercises, mini-challenges were part of the kick-off. The forming of the teams was done either by teachers' decision based on team heterogeneity and challenge interest criteria obtained from participant survey (*Top-Down*) or by participants' decisions during activities (*Bottom-Up)*. ***Team Heterogeneity*** in terms of study field, age, gender, and skills was present during all the years.

Solving any epic challenge requires a lot of knowledge and information to be understood. As the challenge is epic, it is complex by nature and doesn't have a solution yet, one discipline cannot solve it and hence no one person, instructor nor participant will know everything that is needed to solve the problem. ***Team Learning*** draws on identifying team knowledge gaps and closing them. Early on freedom was given to teams to identify uncertainties and gaps in their cumulative knowledge (***Bottom-Up***). Then it evolved to a mixed approach where teachers provide initial questions as a starting point for teams to use, update and expand (***Mix***). Finally, teacher identified knowledge gaps (***Top-Down***) were given as a frame for teams to base their search and learning on.

Team Guidelines on roles, communication and teamwork management were provided. Initially teams were provided with defined ***roles*** (manager, recorder, communications manager) that needed to be assigned and fixed to each team member. In later years these roles were changeable and finally became free to use as needed. Instructions and dedicated activities for ***face-to-face (F2F) communication*** were implemented after the first year to stimulate distributed communication between team members early on. Teams were instructed to have at least one ***weekly team meeting*** and after the first year they adopted a ***weekly reporting*** routine.

Knowledge Curation and Sharing in practice means that the knowledge of an individual, pre-existing, or learned during the program, needs to become the knowledge of the whole team and the future generations. ***Presenting within the team*** was an early instructed practice that became a recommendation. ***Presenting to all participants*** was required at different stages of the program with the final presentation being mandatory. Other ways to share knowledge were public ***blogs and social media posts*** that transformed into a more organized ***private Wiki*** and finally evolved into a ***public Wiki*****,** i.e., a public document that many people can edit.

External Help Recruitment is encouraged as the teacher cannot be the sole source of all information that is needed to solve a challenge that is so complex in nature. Early on teachers were the main organizers of Q&A sessions with experts (***Top-Down***). Later on, this has evolved so that teams were instructed and encouraged to find relevant experts themselves, interview them and mobilize them as needed (***Bottom-Up***). ***Showrooms*** as a way for the students to present their progress and build their own networks were organized by teachers as well.

Early ***Experimentation and Prototype Building*** are the key aspects of the ICED methodology. Over the years the way it has been encouraged and implemented varied depending on availability of budget, materials, components, and experimentation facilities. Early on teams had to mobilize their own networks to acquire needed materials. As the program grew, a budget for experimentation was acquired and dedicated facilities, workshop areas and materials became available for teams to use. This culminated with a dedicated challenge-specific testing environment teams could use to test their final prototypes. During the pandemic quarantine experimentation had to move back to the level of simple experiments that can be done at home.

The ***Skills and Key Concepts*** participants need to learn and acquire to be able to successfully apply the ICED methodology has been evolving as the program was expanding from being taught to NASA engineers to everyone. Figure 1 lists 13 skills and key concepts that were adjusted and iterated over the years based on the participant response.

Pedagogy and Assessment. The teaching was organized so that the contact hours with the teachers are one day a week in the form of a four-hour evening ***workshop***. Portion of the workshop is dedicated for direct instruction when the instructor introduces new concepts, methods or tools and goes through a worked example. The remainder of the four hours is then used for the teams to apply the method to solve the challenge. The last year workshop has been swapped with a ***hackathon*** and ***lectures*** given prior to it. For three years the instruction and assessment were organized in a competency-based manner where each skill/concept was iterated and improved by each participant until 100% mastery. After the mastery was demonstrated, the participant achieved a ***certificate***. For the following three years the certificate assessment system was replaced by an ***exam*** assessment system. One year a ***competition*** was added where the relative performance of the prototypes the students designed and build defined part of the grade of each student. Besides the F2F interaction different ***online tools*** were used as well for sharing learning materials and supporting participant-participant and teacher-participant communication.

5. Discussion

In this section we offer explanations of why certain features remained to be in use for a long time and certain features didn't.

The ***Challenge*** is the key driving force of the program and as such it must be defined well. Firstly, the challenge must be defined to be epic enough and the epicness comes from stating the situation, the goal, and the requirements. Secondly, the challenge must be made such that it truly requires more than one discipline to solve it. Thirdly, the challenge definition should not include any suggestions of what the form of the solution should be. To achieve this, we must use language that focuses on stating the function that needs to be achieved rather than the form that accomplishes the function. Finally, we need to make sure that we are really describing the problem and not the solution. Following these key principles one can use the EC way of approaching problems in any field. Linkage to local R&D resources and availability of experts locally raises the popularity of the program and provides access to subject-matter-experts close by. ***Kick-off Week*** activities should also be designed to promote a psychologically safe environment for the participants to try things and fail, to share opinions and ask questions and to build connections. We observed that practicing ICED skills early-on sets participant expectations and makes the complex engineering tools and concepts more approachable. Hence, ***icebreaker*** activities morphed into early practice and implementation of ICED skills. This also allowed for delivering more course content in a shorter amount of time and compressed the introductory course to only 8 weeks. The kick-off week should end with the formed teams having the first team meeting where participants will make an inventory of their common skills, start finding their knowledge and skill gaps and make a weekly routine for the team. ***Team Heterogeneity*** has remained a key aspect as different people come with different social circles which allows them to share novel ideas which in turn leads to a much larger pool of ideas a team can pull from. With heterogeneity also come difficulties for teachers as their instruction needs to cover different skill levels and learning practices. These difficulties were driving the evolution of the pedagogical practices and the curriculum. Hence the ***skills and key concepts*** and the order in which they have been taught has been evolving as well. Participants learn about many systems engineering concepts and tools such as: systems architecture, functional decomposition, morphological analysis, and decision matrix method. ***System architecture*** and ***mathematical modelling*** have been challenging to instruct to such a wide audience. ***Functional decomposition*** on the other hand has remained an essential part of a clear problem definition. Designing and executing experiments has remained the key aspect of the program. Having a dedicated budget allowed for bringing experiments to a higher level, building prototypes, and testing them. Without budget and facilities, the experiments are forced to stay on a lower level. Also, the amount and level of experimentation depends on the duration of the course. Therefore, to keep the course at the most popular ***5ECTS scope*** the level of experimentation and the amount of content needs to be reduced. When working with diverse teams and with an epic topic no one team member is fully an expert in the topic. Therefore, making an inventory of cumulative team skills and identifying knowledge gaps is a key first step. Furthermore, teams need to create an environment that promotes learning from each other. ***Bottom-Up*** and ***Mixed team learning*** faded away as the course scope became shorter. Teacher identified knowledge gaps (***Top-Down***) has shown to provide a structure that participants can use to frame and expand their search. ***Presentations*** have remained the main way of sharing knowledge and public documentation of knowledge has been present in different forms as well. Certificates as pedagogy and assessment technique were a very successful model from skill mastery point of view. However, the model was not sustainable when the course became shorter to fit the usual university schedule. As the number of participants grew it was no longer possible for one instructor to maintain the number of iterations that was needed for mastery. For these reasons a shift towards the exam as an assessment method was made.

6. Conclusions

The paper presented an overview and evolution of the key features of the ECP in Finland. We have shared how these features have evolved to suit local teaching and a much wider audience. Based on the findings in this paper the most robust features were a Mars themed challenge, focus on Team Heterogeneity, intra- and inter-team knowledge sharing in a form of presentations, Q&A organized by teacher and self-guided expert contacting. Of the skills, Morphological Analysis, PUGH method, Functional Decomposition, simple Experimentation, Knowledge Capture and Presentation Skills were the most robust. It remains to be further explored how to make systems engineering concepts and tools even more appealing to all fields.

Acknowledgements

The authors would like to acknowledge School of Computing and Institute of Photonics at University of Eastern Finland, Karelia University of Applies Sciences, Valamis Group Ltd., and Epic Education Foundation.

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