OmniaScience

Journal of Technology and Science Education
JOTSE, 2022 – 12(1): 274-289 – Online ISSN: 2013-6374 – Print ISSN: 2014-5349
https://doi.org/10.3926/jotse.1324

HOTHOUSING: UTILISING INDUSTRY COLLABORATIVE PROBLEM-SOLVING PRACTICES FOR STEAM IN SCHOOLS

Tony Houghton[1], Zsolt Lavicza[1], Jose Manuel Diego-Mantecón[2], Kristof Fenyvesi[3], Robert Weinhandl[1], Imam Fitri Rahmadi[1]

[1]Linz School of Education, Johannes Kepler University (Austria)
[2]Department of Mathematics, Statistics and Computing, Universidad de Cantabria (Spain)
[3]Finnish Institute for Educational Research, University of Jyväskylä (Finland)

ajh249@gmail.com, lavicza@gmail.com, josemanuel.diego@unican.es, kristof.fenyvesi@jyu.fi, Robert.weinhandl@gmail.com, imam.rahmadi@jku.at

Received June 2021
Accepted January 2022

Abstract

Collaborative Problem Solving (CPS) has been widely used in both industry and in schools over at least the last twenty years. The Industry Hothousing variant of CPS is an intensive, time-constrained workshop-based process to build mutual trust between customers and industry experts in order to synergically develop creative solutions. The main objective of this research is to determine whether and how Hothousing might be used in schools for developing Collaborative Problem Solving and then promoting industry skills. In particular, we seek to establish the degree of structure and support required to unleash student creativity and enhance learning, and the benefits to students and teachers in learning, cross-curricular applicability and time savings. Hothousing for students is based on an intensive series of workshops including face-to-face and on-line collaboration supported by a facilitator. It is student-driven and addresses an open-ended challenge such as: how do I get my friends to love STEAM? Three collaborative problem-solving case studies were examined with different groups of students. Concerning the degree of structure and support, the analyses revealed that student-led intensive collaboration within a trusted framework drives creativity, and it was a good opportunity to experience real life challenges. Positive benefits to students and teachers were the development of technology skills, and Personal Learning and Thinking Skills (PLTS) as well as the enhancement perception of self and STEAM education. These benefits were cross-curricular providing qualitative and efficiency gains including on-line learning.

Keywords – Collaborative problem solving, Creativity, Hothousing, STEAM.

To cite this article:

Houghton, T., Lavicza, Z., Diego-Mantecón, J.M., Fenyvesi, K., Weinhandl, R., & Rahmadi, I.F. (2022). Hothousing: Utilising industry collaborative problem-solving practices for STEAM in schools. *Journal of Technology and Science Education,* 12(1), 274-289. https://doi.org/10.3926/jotse.1324

----

1. Introduction

Much advocacy of Collaborative Problem Solving (CPS) in STEM and STEAM (integrating Science, Technology, Engineering, Maths with the Arts and creativity) rests on the value to industry/country/future of students developing these skills (European Commission, 2018; Thibaut, Knipprath, Dehaene & Depaepe, 2019). For the student, Gateway Qualifications (2020) states that it is an opportunity to develop highly valued technology skills, personal learning and thinking skills (PLTS) and enhanced perception of self (self-esteem, aspirations and respect) and STEAM as a subject and career opportunity (Salmi, Thuneberg, Bogner & Fenyvesi, 2021). In view of its value to both school and industry, can industrial and school expertise in Collaborative Problem Solving be combined and enhanced?

In its adult industry form, customers and industry technology and business experts work together in challenging, time-constrained activities of various formats called Hothousing (Ideasfirst, 2021; TU Dublin Hothouse, 2021; Craft Case Hothouse, 2021; BT.com.2021). Typically, a workshop is run over three or four days and small groups of customers and industry experts work together to go from problem challenge to solution design and development up to a demonstrable, working prototype solution. The intensive, group activity builds mutual trust between industry and customers who develop creative solutions. But is this intensive, time-constrained, pressurized activity appropriate to students - or does the student require structured activities with teacher-designed tasks being explicitly taught learning skills such as how to take turns, different roles and reaching agreement? In addition, can CPS be mapped beneficially to the curriculum and be undertaken in class time? In cost benefit terms, is it extra work for the teacher? Or may it have a cross-curricular benefit addressing multiple areas of the curriculum at the same time and so have efficiency gains? For the student, is the extra effort worth it? In particular, may it directly help 'get the grades'? It might be assumed that students will react positively to a stimulating challenge as in affective learning; learning that relates to the learner's interests, attitudes, and motivations (Picard, 2004; Diego-Mantecon, Arcera, Blanco & Lavicza, 2019; Diego-Mantecon, Prodromou, Lavicza, Blanco & Ortiz-Laso, 2021). But Weinhandl, Lavicza, Houghton and Hohenwarter (2020) found also that an important factor in learners' extrinsic motivation is the perceived positive cost-benefit, and in particular the contribution to their tests/grades. The overall objective of this case study research is to determine whether, and to what extent, hothousing might be used in schools both for developing Collaborative Problem Solving (CPS) and promoting highly valued industry skills. Within this objective, two questions are established: (1) What is the degree of structure and support required to unleash student creativity and enhance learning? (2) What are the benefits of implementing hothousing to both students and teachers in terms of learning, cross-curricular applicability and time savings?

To answer these questions, three collaborative problem-solving case studies were examined which involved a wide range of student ages and abilities, reported positive questionnaire feedback, as well as high completion rates and good student project outcomes. The three projects (Global Hothousing, Orbit, and KIKS) all feature Hothousing; an intensive workshop technique relying on trust widely used in industry in various formats. It was not the widely criticised Hothousing intensive education of a child to a high level at an earlier age than is usual (Ricci, 2015). In the following, a brief overview of both CPS in industry and schools, over the last twenty years, is outlined together with potential student educational benefits. It noteworthy that although there is extensive academic literature on CPS, this is not so for hothousing perhaps because these are commercial industry projects as referenced above.

2. Hothousing for Adults and Children

BT (British Telecom) has a long history going back twenty years in using Hothousing as a way of understanding customer requirements and developing solutions by inviting customers and BT experts to work together, most recently described in 'How BT Innovates (BT.com, 2021). A programme called 'Understanding the Young Customer', a variant of adult Housing, was used in the BT Global Hothouse project which featured twenty-four 14-16-year-old students of mixed abilities working with industry business and technology experts to explore future products and services, focusing on mobile technologies (Houghton, 2005). There were three face-to-face 3-hour meetings over six months. Years later, the

Cambridge ORBIT project asked twelve gifted 15-year-old students to develop GeoGebra (mathematics software) projects for other less able/enthusiastic peers, with three 2-hour meetings over the two-month summer holiday period (Houghton, 2012). The KIKS (Kids Inspiring Kids in STEAM) EU project also engaged four European countries over a two-year period with a total of 40 schools and approximately 400 students, including three special needs schools (Houghton, Oldknow, Diego-Mantecón, Fenyvesi, Crilly & Lavicza, 2019; Fenyvesi, Houghton, Diego-Mantecón, Crilly, Oldknow, Lavicza et al., 2017). Students between 13-16 of very different abilities were asked to develop STEAM projects over a range of technologies for their fellow students via both physical face-to-face and on-line collaboration (Diego-Mantecón, Blanco, Ortiz-Laso & Lavicza, 2021).

Hothousing is an intensive challenging variant of CPS in which trust is key, which is widely used in industry. Collier (2016) states that *"collaborative problem-solving occurs as you collaborate with other people to exchange information, ideas or perspectives. Any individual, team or company can take advantage of this approach"*. Intensity is another key component of the approach. Wiltschnig, Christensen and Ball (2013) found that, in product development, the co-evolution (i.e., the development of ideas working together) heightens creativity. They observed also that the engine of creativity in collaborative design was promoted by typical intensive activities such as brainstorming and problem solving. Trust is also required for this to happen. The building of mutual trust is an important component of creativity-collaboration in the challenging world of union management bargaining (Basadur, Pringle, Speranzini & Bacot, 2000). Basadur et al. (2000) stated that the "*creative process simultaneously builds trust and provides a pathway to collaborative, creative, work ...the opening of minds in a non-threatening way"* Participants need to be supported during the process, as they may be anxious or stressed. Perry and Ablon (2019) claim the need to ensure success across various mental health settings while Bassadur et al. (2000) suggest a process designed to foster trust in turn, leading to innovative solutions and win-win satisfaction.

Hothousing is a well-established business technique consisting of a series of intensive workshops in which a facilitator initially leads, then gradually but quickly hands over control and supports competitive groups of employees and customers together to come up with their own creative business solutions. Trust and belief in the intensive, pressured process and in each other is key to business and technology experts and customers working confidently together, in addition to sharing often confidential information. CPS in various formats has been widely used in schools and has a long history. For example, Hennessey and Murphy (1999) identified teachers who engendered a problem-solving culture in their classroom. Rojas-Drummond, Mazón, Fernández and Wegerif (2006) identified and described explicit reasoning, creativity and co-construction in primary school children's collaborative activities. Lander (2016) explored the mutual benefits of student peer-to-peer teaching and suggests this should be built into the curriculum, in-class and after school activities. Aspects of CPS are found in the flipped classroom where: students play the role of active learners and make good use of the assistance given by experts to elucidate relevant concepts; teachers become facilitators and assistants, instead of instructors (Hwang, Lai & Wang, 2015). Similarly, in Flipped Learning group space is transformed into a dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter (Association of Flipped Learning Network, 2014).

STEAM CPS offers educational situations where both individual and social skills are required: individual technology skills, and personal learning and thinking skills (PLTS), specially for collaborating with others. The development of PLTS implies Creative Thinking, Effective Participation, and Team Working (Gateway Qualifications, 2020). It is noteworthy that the European Union 2020 (O'Shea, Frohlich Hougaard, McGrath, Grainger Clemson, Vrhovski & Kozak, 2020) describes 'personal, social and learning-to-learn competence' as a key competence for lifelong learning. It should be pointed out, however, that Dabell (2018) considers PLTS as an educational fad: "*not everyone will function as a team player nor should they aspire to be – lots of successful people work as independent spirits, mavericks and solo agents – not all students are happy to be in a team"*. If this is so, the Hothousing approach has to somehow cater for this, making students confident and happy, rather than anxious and/or disruptive, to be in the team.

The common features of the Hothousing creative, collaborative problem-solving process deployed across the three projects were promoted by means of intensive workshop events, as suggested in Figure 1, with the teacher as facilitator, supporting activities led by students.

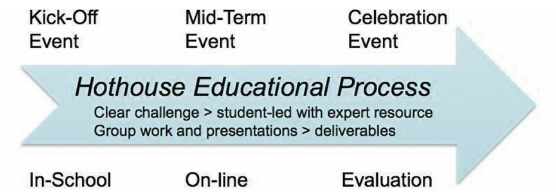

Figure 1. Hothousing Process

There were typically kick-off, mid-term and celebratory workshop events with the overall process duration of a day, week or year with a blend of physical and on-line collaboration. The first workshop of two- or three-hour duration had a clear structure and was initially led by the facilitator (teacher) with control and responsibility gradually handed over to students. Subsequent workshops were more loosely structured and increasingly driven by students. In the first workshop, students were presented with an open-ended challenge such as 'How do I get my friends to LOVE STEAM education?' 'How do we get light into our partner school homes in India?' or 'What's the next BIG mobile product?' They were asked to form school groups and take three minutes to discuss their initial thoughts on the challenge. They were then asked to present their ideas in sixty seconds. The intensive kick-off workshop agenda focuses on group work and presentations, also working with multi-disciplinary experts from academic, business and/or other organisations.

The process was not about creativity in a vacuum. There was a specific technology teach-in as part of the agenda. This addressed mobile technology or maths software tools such as GeoGebra and Tracker (video analysis to study the maths and science of fight), as in case study 2. Computing challenges were proposed in case study 3, using micro bit computers for traffic management as part of a project of future transport. Students organised themselves, learned new technologies, and engaged in short group discussions and presentations. Teachers did not put the students into groups nor allocate roles, they did this themselves. Nor were they taught creativity, it was assumed the intensity and trusted collaboration will unleash creativity and give them the confidence to learn by struggling with the challenge and how they approach it. This is in contrast to the teacher-led UK NESTA (Luckin, Baines, Cukurova & Holmes, 2017), educational organisation that advises teachers to hint but do not help encourage rather than direct the group's attempts to do the task, teach them to take turns, give everyone a role, think about the question and reach a consensus. It is also different to that of the Education Endowment Foundation (EEF) (2019) Toolkit on Collaborative learning which states:

> '*Effective collaborative learning requires much more than just sitting pupils together and asking them to work in a group; structured approaches with well-designed tasks lead to the greatest learning gains. Pupils need support and practice to work together; it does not happen automatically. Tasks need to be designed carefully so that working together is effective and efficient, otherwise some pupils will try to work on their own.*'

In contrast, the Hothousing approach assumes much of this will happen based on group dynamics and that the opportunity to work under intensive conditions and time constraints is a valuable opportunity to experience real life challenges in a safe and trusting environment. Indeed, creativity may be unnecessarily constrained by too much teacher direction.

3. Method

The method used for this study was to examine three existing case studies and elicit insights from them. The studies were conducted over a number of years in different ways for differing requirements. Yin (2012) found that the strengths and weaknesses of case study research need clarification, and it is clear that the richness and practical experience of these real-life case studies is balanced by the need for caution on generalisability and difficulties in drawing definite cause/effects (Miller, 2016). To address this, three overlapping case studies are examined which have the common Hothousing framework and process. Insights are drawn by comparing and contrasting them, driven by the literature presented in the previous section and then in discussion.

The first project, Global Hothousing, brought students together with British Telecom, CISCO, Tesco and DHL experts. As part of a project to explore customer requirements for future product and service design exploiting mobile technology, the business objective was to 'Understand the Young Customer' in a variant of the adult version. The second project at Cambridge University took gifted students and injected a considerable technology teach-in to the process, learning to use GeoGebra modelling software. The third project was an extensive four-country, European Commission funded ERASMUS+ project which included secondary school students of a wide range of abilities including special needs, and featured local and international on-line collaboration in different technology-based activities.

3.1. Global Hothousing

Hothousing is BT's way of kick-starting IT products and services development (BT.com, 2021). It brings together customers, BT business experts and technology developers to work in competing teams in an intensive, competitive, yet fun environment over three consecutive 12-hour days. The objective is that this 'hot' environment fosters creativity and energizes teams to come up with a prototype, accompanying specification and plan to develop the product or service over the subsequent 90 days. The current work aimed to carry this stage further to 'Working with the Young Customer'. To do so, it was decided to start with BT's Hothousing approach, hitherto used to working with adult customers, and ask whether Industry Hothousing Practices can be applied to STEAM Collaborative Problem Solving with school students, what form the school student variant would take, and the benefits to students.

Adult Hothousing consists of competing teams over three consecutive, long days addressing the same business challenge, or 'business problem statement' in Hothouse terms. This was judged by BT and teachers as not feasible for 14-16-year-olds. Accordingly, the Hothousing variant devised for twenty-four students took place over three 3-hour sessions, once per month spread over six months, whilst retaining the essential intense, competitive, fun nature. The students and BT volunteers were split into 4 competing mixed teams each of 10 people (i.e., different schools and BT in the same team). Each team had a different idea to explore. The ideas were simple one-line statements that originated at a previous visit to the schools undertaken by BT people, when the students were asked to simply come up with four ideas for the future. The four ideas were:

- Techno Classroom – virtual classroom of the future allowing remote collaboration.
- Supermarket Trolley – the active uses to which it might be put.
- Multipurpose Handheld device – meeting the needs of a 14-16-year-old customer
- Active Road facility/device – active road and the potential benefits

The teams had 3 hours to develop their ideas and to prepare a 10 -minute presentation/demonstration. As part of the group work, BT experts provided mobile technology teach-ins as or if required on Bluetooth, 3G, WLAN (Figure 2). Also, the students were invited to visit the BT Research Laboratories Customer Showcase featuring future shops, banks, health and transport that included hands-on mobile prototypes. The final demonstrations featured four working prototypes developed with the industry experts but strongly reflecting student - led ideas development (Figure 3). This will be explored more closely in the results and discussion section.

Figure 2. BT Hothousing

Figure 3. BT Hothousing prototypes

3.2. ORBIT

At the University of Cambridge, twelve 15-year-old students were asked to develop 'real life' GeoGebra mathematical software applications of their choice for a wide range of users (both other students and teachers) of varying technical ability and confidence. The two month-long activities consisted of 3 two-hour workshops interspersed with home-working and on-line collaboration. In addition to excellent GeoGebra applications per se, the students developed their communication and collaboration skills and enhanced their (measured) perception of the importance of technological education. Because GeoGebra, and indeed STEM teachers are relatively thin on the ground, the approach taken was for the teacher to initially facilitate the workshops working with the technology (GeoGebra) expert. The three sessions became gradually less structured as the students became more confident using the expert as or if required. The first session featured a hands-on GeoGebra tutorial and discussion of on-line communication possibilities led by Professor Adrian Oldknow. The initial GeoGebra tutorial session featured 'real life' examples such as mathematical modelling and visualization from photographs of patterns and structure in flowers and architecture; exercises such as 'maths aerobics' where students model algebraic functions kinaesthetically; and data analysis and exploration such as from astronomy (Kepler's 3rd law) and athletic performance (Usain Bolt's 100m sprints). Realistic examples such as these, or from students' previous work, are essential to get the ball rolling. Following this, the next sessions and onus was very much on the student's own initiative. The project below (Figure 4) is described in the student's own words:

Flying paper planes for age group years 5-9

> *It's not too technical, and it is very visual and interactive and simple to understand. […] I used GeoGebra to produce an animated tutorial of an origami piece (such as a paper aeroplane). Once the plane has been made, experiments with throwing the plane show that it does not fly in a parabolic curve, as a ball would.*
>
> *I have produced an interactive GeoGebra spreadsheet to show how a ball would fall. Another GeoGebra spreadsheet demonstrates the Flight trajectory of the plane. I have also produced a word document describing very simply, how the plane flies.*

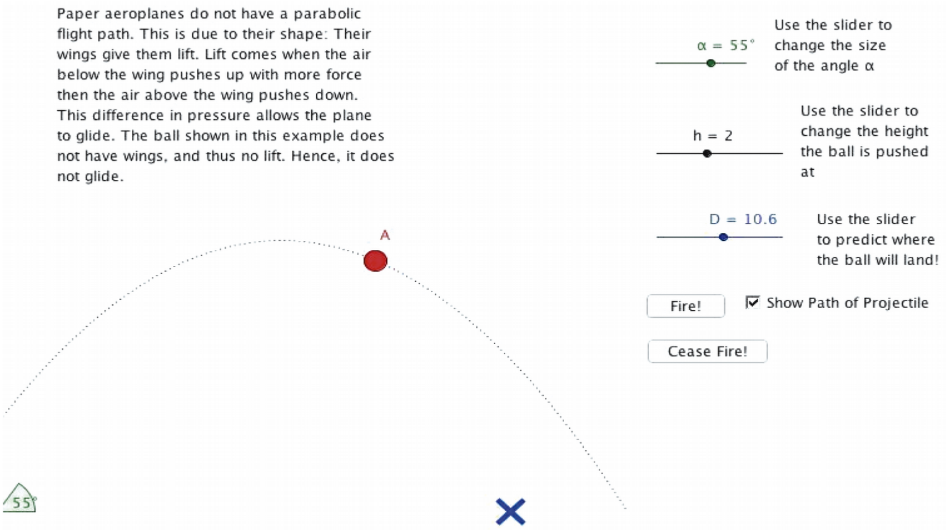

Figure 4. Flying paper planes

3.3. KIKS

The KIKS project was set to school pupils as a challenge: *How would you get your schoolmates to LOVE STEAM?* The following description is based on Houghton et al. (2019). This international Erasmus+ KIKS project supported Kids Inspiring Kids in STEAM by a three-stage process of Hothousing (to creatively develop ideas), Local Challenges (to develop those ideas into projects and deliver them to other students) and International Collaboration (sharing and working together). In the UK, Finland, Spain, and Hungary there were a total of approximately 400 students – four countries, five schools, each with twenty students working in groups of four to six members. As part of this there was considerable on-line interaction (Diego-Mantecón, Blanco, González, Istúriz, Gorgal, González-Ruiz et al., 2017). The process began with a tightly structured Hothouse Multi-School Kick-Off agenda led by teachers including relevant technology teach-ins. Control was gradually handed over to the student and followed by less structured activities in which the students took control and responsibility both back in school in Local Challenges and then in International Collaboration. Micro-bits were used in many projects and various 'Introductions to Micro-bit' and 'How to…' documents were produced. In one KIKS kick-off meeting, the discussion was the 'grand challenges' for future engineers, one of which is future cities, future transport and driverless vehicles, and the wider challenges of driverless cars for society: a fleet of line following buggies and a small-town road system of Micro-bit-controlled traffic lights, as can be seen in Figure 5. Extra KIKS activities to the ones described here can be found in Diego-Mantecón, Blanco et al. (2017) and (Diego-Mantecón, Prodromou et al., 2021). The projects of the forty schools were presented in a WIKI and led to international collaboration featuring twenty-one projects and six multi-country collaborations.

This international project was the largest of the three examples and provided a wealth of information in particular on inclusion and online which will be presented in the next sections.

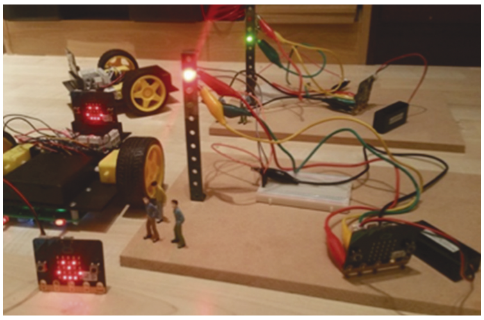

Figure 5. Micro-bit traffic lights

4. Results

Taken together, the three projects gave considerable data to identify the degree of structure and support required to unleash student creativity and enhance learning. The benefits of implementing hothousing to both students and teachers in terms of learning, cross-curricular applicability and time savings were also identified with such a data set.

4.1. Degree of Structure to Unleash Student Creativity and Collaboration

During a BT Global Hothousing session, short video recordings were made of the teams. One recording was a 2-minute sample of the team working together. The dialogue can be seen in Table 1.

Student Summary: *(S1) Our task is the Hendrix of Technology – a multipurpose handheld device*
BT Mentor: *BT Does it have to do everything?*
Students address the basics: *(S1) Start off with the base object and upgradeable. (S3) Starts off basic, doing everything really well, then if you wanted it to... (S4) On the physical side, press a button and a keyboard pops up.*
BT Mentoring building on the above: *BT KISS – do you know what that means? Keep It Simple Stupid! (laughter) BT So what's the thing we want it to really do?*
Students offer ideas on what it should do: *(S2) Big screen colour. (S1) Simple phone. (S3) Communications. (S2) Games. (S3) Upgradeable and Summarizes idea so far. (S2) Video TV channels.*
Student iVine arm wear concept emerges: *(S4) Reminds me of gladiatorial armor – arm shield. (S4) If we use the iVine idea, wire running up arm instead of Bluetooth.*
Students address user interface possibilities: *(S2) Use a scroll, up and down, hit the button, select, down, down, down, select. (S3) Actually you only need one wheel or... (S1) Two buttons or even One button – one click – don't need massively complex array of buttons. (S2) Well simple. (S4) Big screen unfold available via plug-in (demonstrating with hand gestures).*

Table 1. iVine Idea Generation

As the dialogue Table I shows, there are 17 statements or ideas from the students and 3 mentoring comments from BT people. The dialogue sequence starts with a summary statement of the idea from Student 1 (S1). It continues with a BT mentoring item to kick ideas off (BT). The students S1, S3, S4 then build up the idea of starting with a basic device. BT makes two mentoring statements. Then S2, S1, S3, S2, S3, S3, and S2 offer ideas on what it should do. Then, S4 comes up with the iVine idea and attachment to the arm. The students S2, S3, S1, S2, and S4 then address user interface possibilities. This sequence in Table 1 represents the students' ideas generation. It was found that rapid, productive collaboration between BT people and students took place after approximately 30 minutes. Children and teachers liked the tough 'Hot' approach of hard work and play, as the following statements from both agents, and the BT Team members, and the BT Customer Experience Consultant corroborate:

- *Lots of pressure, focused on winning, well, makes us work hard...Elated... brilliant first step.* (Students)
- *Interaction of experts, managing and coaching, so exciting. Brilliant learning opportunity, the event being based on a real hothouse approach.* (Teachers)
- *Amazed with ideas they came out with. They're experts! Amazing!* (BT Team members)
- *Highly skilled presentations attained a professional level.* (BT Customer Experience Consultant)

Regarding collaboration from on-line and inclusion perspectives, the KIKS Hothousing process embraced those students naturally inclined to work in groups and those not so inclined for whatever reasons as suggested by Dabell (2018). KIKS provided a rich diversity of schools. The UK provided 100% state schools including three special needs schools. There was an 88% school completion rate; i.e., from workshop through to international collaboration suggesting that very different types of schools and pupils benefited from the process. There were 21 on-line collaboration projects and 6 international collaborations with 400 unique visitors per month - noting that the international collaborations were 100% online. Inclusion and on-line often go together in students that often required to work from home as in special needs schools, and the Covid-19 2020 pandemic. It has been previously noted that some students do not feel comfortable in teams, as described in face-to-face collaborations by Diego-Mantecón, Prodromou et al. (2021), however the fact that the teams all completed successful projects suggests that the process could cope with this. Overall, the students were indeed able to lead, and the intense activity led to strong creativity and collaboration, both face-to-face and online.

4.2. Benefits

The three Hothousing case studies illustrated a wide range of learning covering technology skills, PLTS and enhanced perception. This can be achieved within and across the curriculum resulting in time saving benefits, rather than placing extra burdens or costs on teachers.

4.2.1. Learning: Technology Skills, PLTS and Enhanced Perception

In the ORBIT project, a wide range of collaborative face-to-face and on-line learning took place, together with enhanced perception of self and STEAM. Technology skills (GeoGebra) and understanding (Flight) were developed, and positive benefits and perceptions gathered form the students:

- *Fun and exciting using the GeoGebra software.*
- *Have learnt many new skills and facts whilst participating in this project.*
- *GeoGebra is really useful!*
- *I developed my understanding of how planes fly.*

Project development skills were flexed:

- *The project taught me how to facilitate a long-term project. This project has helped me to learn how to put ideas together into one coherent project.*

The benefits of collaborative working were also experienced by the students. The following represents one of the descriptions given by a subject during an interview:

- Sharing *ideas was very helpful in generating concepts for my project. I enjoyed the independence of the project and introduced us to each other to ensure we were comfortable with each other. I found asking others very helpful, as they share ideas with me, which I would not have previously thought of.*

Students' commentaries as the one presented below makes us to believe that targeted presentation skills were also nurtured.

- *This project has allowed me to create and present my ideas to others…How to present it in a way suitable for young people to use and interact with.*

In the Global Hothouse project, one of the schools used a Personal Learning and Thinking Skills (PLTS) Record Card in which students, peers, and teachers made assessments of their own and others achievements, at the same time encouraging reflection and appreciation of the following PLTS skills (Gateway Qualifications, 2020), backed by evidence as the next example-quote reads:

- *I AM a team player and also can work on my own initiative, think about what I am doing and manage myself a bit better.*

In an attempt to examine perception changes in both self and STEAM, pupils were asked five technology related perception questions on a five-point scale (1-low, 5-high), for example: *To what extent do you feel that teamworking skills are important in technological activities? and To what extent do you feel communication and collaboration skills are important in technological activities?* Further questions can be seen in Table 2:

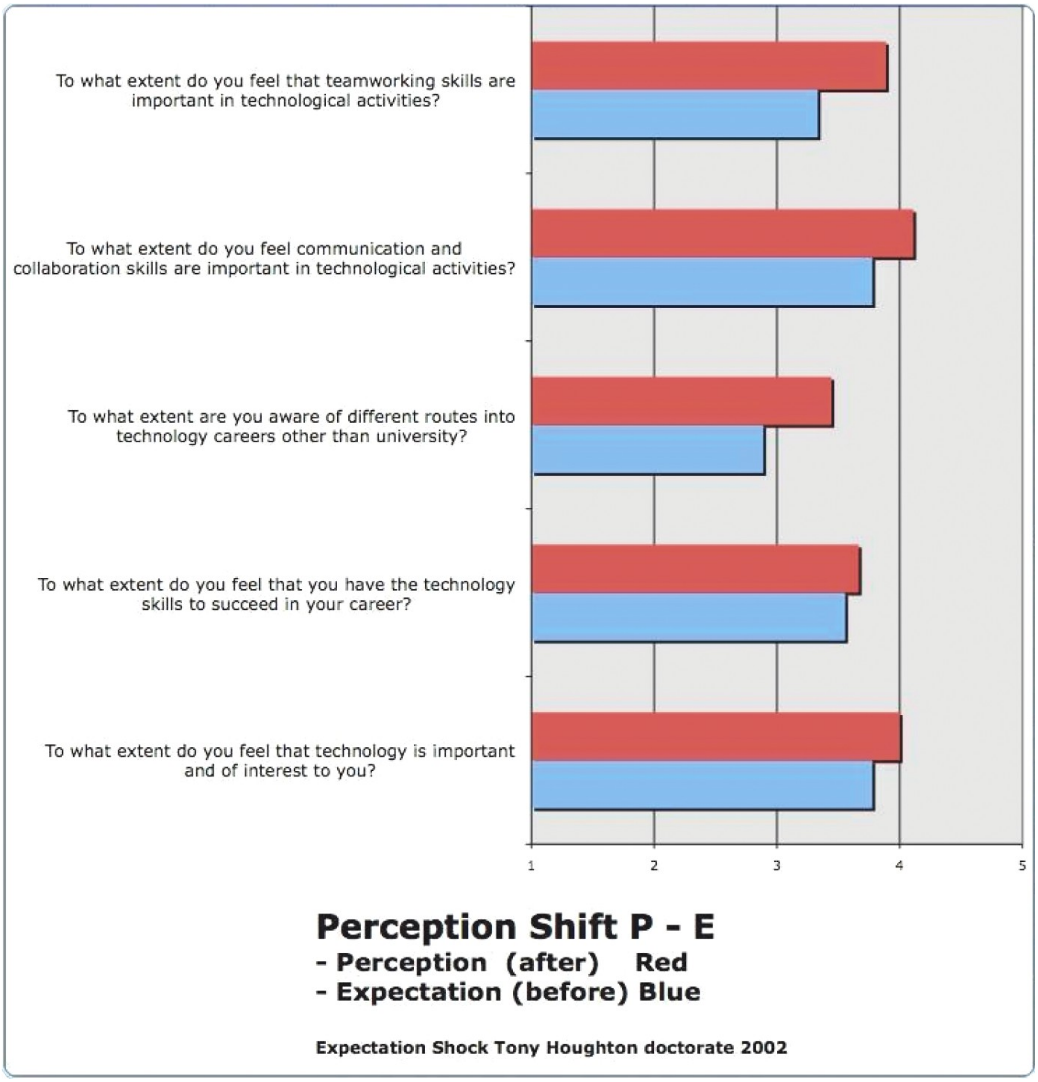

Table 2. Perception enhancements group profile

The chart shows the group profile before (blue) and after (red) the programme. The after-programme scores (red) show clear enhancements in their perception, particularly of the importance of technology, and the associated necessary communication and team working skills. Individual perception shifts were in some cases high indicating that the activity had a considerable effect on the student, in some cases zero, for example where a student already had a high perception. Thus, skills development in technology and PLTS was achieved, alongside enhanced perception of self and of STEAM.

4.2.2. Cross-Curricular Applicability and Time Savings

Accepting from the above that CPS is a valuable educational activity, it rests to be established whether this is best undertaken as an out-of-hours (or club activity) or whether it can be as part of the curricular requirement. PISA and EU2020 all recommend that children's education should foster enjoyment, self-belief, and the stamina to address complex problems and situations in STEAM subjects (OECD, 2018). This is also a requirement of the International Baccalaureate: *"Educational approaches should feature creative problem-solving challenges including societal factors/needs."* and at least one interdisciplinary unit with two subject groups (IB, 2020). The following shows extracts from the English National Curriculum for key Stage 3 (age 11-14), in Computing, Mathematics, English, Science, Design and Technology, and Art and Design (Table 3):

Computing programmes of study (key stages 3 and 4 National curriculum in England September 2013)
Undertake creative projects that involve selecting, using, and combining multiple applications, preferably across a range of devices, to achieve challenging goals, including collecting and analysing data and meeting the needs of known users.
Mathematics **programmes of study** (key stage 3 National curriculum in England)
Develop fluency; mathematical reasoning and competence in solving increasingly sophisticated problems... apply their mathematical knowledge in science, geography, computing and other subjects.
English programmes of study (key stage 3 and 4 National curriculum in England September 2013)
Competent in the arts of speaking and listening, making formal presentations, demonstrating to others and participating in debate...speak confidently and effectively in a range of formal and informal contexts,
Supporting a point of view by referring to evidence...recognising the possibility of and evaluating different responses... making an informed personal response that derives from analysis and evaluation
Science programmes of study (key stage 3 National curriculum in England September 2013)
Present reasoned explanations, including explaining data in relation to predictions and hypotheses
Design and technology programmes of study (key stage 3 National curriculum in England)
Critique, evaluate and test their ideas and products and the work of others, take into account the views of intended users and other interested groups
Art and design programmes of study (key stage 3 National curriculum in England)
Analyse and evaluate their own work, and that of others, in order to strengthen the visual impact or applications of their work

Table 3. Mapping Hothousing to English National Curriculum

It will be seen that CPS maps onto a wide range of curricular requirements. In each project the students were introduced to a creative collaborative problem-solving challenge, which mapped to the *Computing* programme (focusing on creative challenges with project planning skills and thinking about the needs of others) and the *Maths* programme (applying their knowledge to a wide range of problems). The presentations and demonstrations mapped to the *English* programme. The *Science, Design and Technology and Art* programmes mapped onto collaboration, promoting their own and others' ideas, which in the three case studies included meeting other students' requirements by devising projects to interest them, peer-to-peer learning, and student ambassador roles. The integrated approach provided qualitative improvements; in the English Key Stage 4 (*recognising the possibility of and evaluating different responses... and making an informed personal response that derives from analysis and evaluation)* might be considered more scientific and analytical than in the Science curriculum itself, which makes no mention of students generating their own hypotheses and or reflecting (Vine, 2020). Combining the two (English and Science) therefore creates a deeper analysis. There were also efficiency gains as different areas of the curriculum were covered at the same time, rather than separately. In short, there was evident cross-curricular ability and potential time savings.

5. Discussion

Finding, from the above, that Industry Hothousing Practices can be applied to STEAM Collaborative Problem Solving with school students, we address the two specific research objectives.

What is the degree of structure and support required to unleash student creativity and enhance learning?

The analyses showed student-led creativity and collaboration. It was found that students were quickly able to take over the activity. They were able to both lead and collaborate. Students enjoyed the intensive approach and there were demonstrably high levels of creativity. Clearly, there is an important role of the teacher as facilitator to prepare the students for the experience and to step in if/when problems occur. However, the response of both students and teachers suggests that the 'less structure the better' works within a safe, trusting environment, less than that suggested by NESTA (Luckin et al., 2017) or the Education Endowment Foundation (EEF) (2019) Toolkit on Collaborative learning, and more in line with Flipped Classroom (Hwang et al., 2015), Flipped Learning (Association of Flipped Learning Network, 2014) and on-line synchronous and asynchronous flipped learning (Rindaningsih, Findawati, Hastuti & Fahyuni, 2021).

This student-driven, intensive, collaborative process can be both face-to-face and online. It was found that the KIKS variant was suited to very different schools and students. It appears that the safe exploration of individual and social skills is of benefit to students. On-line collaboration was successful, of which most was a follow-on from face-to-face initial workshops. The international collaboration was 100% online. The success of the on-line experience is of extra interest because there are many special needs students who learn mainly on-line. So, inclusion and on-line learning are often found together. In the light of the 2020 Covid experience, on-line may have more potential than we thought in making both teachers and students more confident in the on-line experience. Indeed, the findings of Weinhandl et al. (2020) from teaching mathematics in times of extreme isolation, mirror closely the key features of Hothousing: problems or tasks as learning triggers, learning as a social as well as individual process, and perceived positive cost-benefit analysis of learning mathematics as key to students' learning success. This suggests that the CPS Hothousing approach hitherto mainly face-to-face may have powerful application to inclusive, on-line working.

What are the benefits of implementing hothousing to both students and teachers in terms of learning, cross-curricular applicability and time savings?

The cross curricular contribution of CPS Hothousing was demonstrated, giving confidence to teachers and students that their time and engagement is worthwhile. Students were given opportunities to develop both technology skills and personal learning and thinking skills, which led to enhanced perception of self and STEAM. GeoGebra is complex software and a challenge enough in itself, together with learning about Flight. In parallel, the opportunity to collaborate helped project skills and working together. These can be successfully mapped onto a national curriculum as well as PISA and EU2020 requirements. In the iSTEAMPLUS Flight project of teacher Vine (2020), a similar mapping can be made. The problem-solving challenge was to build the best individual glider and understand the impact of the aviation industry. The students got various technology teach-ins covering Flight maths and science, and they worked on micro bit computing and GeoGebra maths software, thus contributing to both the *Computing* and *Mathematics* programmes.

They worked in teams designing their gliders and experience *Science, Design and Technology* activities to develop and evaluate their individual solutions. A major part of the exercise was communication and collaboration within the team extending to student ambassador roles and peer-to-peer teaching of others. They were challenged to extend their work to consider the impact of aviation on people, the environment, culture and language, and make both individual and team presentations, which map the *English programme and* in particular the above key stage 4 personal responses. Last but not least they were challenged to extend their activities to Art. In calling his project iSTEAMPLUS, Vine (2000) extents the 'plus' to the creative Arts and PE (Physical Education), finding that Arts has a great effect on motivation and enthusiasm, students get to act, and feel physically and emotionally. The teamwork provides also valuable social and problem-solving lessons that inspire students to work further. Key is that this becomes flipped learning: students demand to be told or taught. This helps them understand or build their projects: teachers are no longer seen as imposing burdens saying 'we think you ought to learn this'. They drive for learning is switched, the student becomes the driver of his or her own learning.

6. Conclusions and Further Work

From the three case studies using Hothousing, it appears that a variant of Industry Hothousing can indeed be used successfully with students and that less structure may be needed than widely thought. Indeed, we have to be careful not to restrict creativity. It has been demonstrated that intensive collaboration drives creativity. Failure/stress/strain can be positive and provides opportunity to experience real life challenges in a safe environment. Intensity and trust plus facilitator replace a more teacher-led activity. The positive benefit to students and teachers covers technology skills, PLTS and enhanced perception of both self and STEAM, and are cross-curricular. Inclusion and the benefit of on-line learning are linked, and using technology may be more powerful and more confidently used than previously thought, in the light of the COVID experience. The CPS Hothousing process can contribute to this increasing use and acceptance.

It will be noted that, from a cost benefit perspective, benefits were established but cost was not. This cost may include real or perceived teacher effort and time requirements with new technologies and integrated course development over and above meeting the needs of the curriculum. The projects were student-driven but the KIKS study acknowledged that projects would not happen if it were not for the support of teachers. Although it may be assumed that teachers on the KIKS project were already convinced of the overall benefit of these Hothousing STEAM activities, it is clear that this cannot be assumed for all teachers, as also suggested by Diego-Mantecon, Blanco et al. (2021). Accordingly, a follow-on project STEAMTeach (STEAM Education for Teaching Professionalism, 2020) focuses on teachers' in- and pre-service professional development addressing real and perceived challenges including teacher confidence, concerns and pedagogical creativity (Szabó, Burnard, Harris, Fenyvesi, Soundararaj & Kangasvieri, 2021) in subject integration, technology such as 3D printing, meeting the curricular requirement, time constraints, assessment and student-perceived benefit.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

This study has received support from the Erasmus+ Programme of the European Union [2020-1-ES01-KA201-082102 (STEAM Education for Teaching Professionalism) Key Action 2]. The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

References

Association of Flipped Learning Network (2014). *What is flipped learning?* Available at: https://flippedlearning.org/definition-of-flipped-learning/

Basadur, M., Pringle, P., Speranzini, G., & Bacot, M. (2000). Collaborative Problem Solving Through Creativity in Problem Definition: Expanding the Pie. *Creativity and Innovation Management*, 9(1), 54-76. https://doi.org/10.1111/1467-8691.00157

BT.com (2021). *How BT Innovates.* Available at: https://www.bt.com/about/innovation/how-bt-innovates

Collier, C. (2016). *How To Adopt A Collaborative Problem-Solving Approach Through 'Yes, And' Thinking*? Forbes. Available at: https://www.forbes.com/sites/forbescoachescouncil/2016/11/21/how-to-adopt-a-collaborative-problem-solving-approach-through-yes-and-thinking/

Craft Case Hothouse (2021). Available at: https://www.thecreativeindustries.co.uk/site-content/industries-craft-craft-case-studies-craft-case-hothouse

Dabell, J. (2018). *Educational Fad: Personal, Learning and Thinking Skill (PLTS)*. Teacher Toolkit. Available at: https://www.teachertoolkit.co.uk/2018/07/01/educational-fad-12/

Diego-Mantecón, J.M., Arcera, O., Blanco, T.F., & Lavicza, Z. (2019). An engineering technology problem-solving approach for modifying student mathematics-related beliefs: building a robot to solve a Rubik's cube. *International Journal for Technology in Mathematics Education,* 26(2), 55-64. https://doi.org/10.1564/tme_v26.2.02

Diego-Mantecón, J.M., Blanco, T.F., González, M.J., Istúriz, M.P., Gorgal, A., González-Ruiz, I. et al. (2017). Proyecto KIKS (Kids Inspiring Kids for STEAM). In Federación Española de Sociedades de Profesores de Matemáticas (Ed.), *VIII Congreso Iberoamericano de Educación Matemática. Libro de Actas* (87-94). Madrid, España: FESPM.

Diego-Mantecon, J.M., Prodromou, T., Lavicza, Z., Blanco, T.F., & Ortiz-Laso, Z. (2021). An attempt to evaluate STEAM project-based instruction from a school mathematics perspective. *ZDM Mathematics Education,* 53(5), 1137-1148. https://doi.org/10.1007/s11858-021-01303-9

Diego-Mantecón, J., Blanco, T., Ortiz-Laso, Z., & Lavicza, Z. (2021). STEAM projects with KIKS format for developing key competences. [Proyectos STEAM con formato KIKS para el desarrollo de competencias clave]. *Comunicar,* 66, 33-43. https://doi.org/10.3916/C66-2021-03

Education Endowment Foundation (EEF) (2019). *Collaborative Learning Approaches*. Available at: https://educationendowmentfoundation.org.uk/evidence-summaries/teaching-learning-toolkit/collaborative-learning

European Commission (2018). *Council Recommendation of 22 May 2018 on key competences for lifelong learning.* Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32018H0604(01)

Fenyvesi, K., Houghton, T., Diego-Mantecón, J.M., Crilly, E., Oldknow, A., Lavicza, Z. et al. (2017). Kids Inspire Kids for STEAM. *The STEAM Journal,* 3(1). https://doi.org/10.5642/steam.20170301.21

Gateway Qualifications (2020). *Personal Learning & Thinking Skills (PLTS)*. Gateway Qualifications. Available at: https://www.gatewayqualifications.org.uk/qualification-area/personal-social-development/personal-learning-thinking/

Hennessy, S., & Murphy, P. (1999). The Potential for Collaborative Problem Solving in Design and Technology. *International Journal of Technology and Design Education*, 9(1), 1-36. https://doi.org/10.1023/A:1008855526312

Houghton, T. (2005). *Understanding Customer Behaviour to Enhance Telecommunications Networks and Services Design.* Doctoral Thesis. University College London.

Houghton, T. (2012). *GeoGebra STEM Exploration*. Available at: https://oer.educ.cam.ac.uk/wiki/GeoGebraSTEM_exploration_day

Houghton, T., Oldknow, A., Diego-Mantecón, J.M., Fenyvesi, K., Crilly, E., & Lavicza, Z. (2019). KIKS Creativity and Technology for All. *Open Education Studies*, 1(1), 198-208. https://doi.org/10.1515/edu-2019-0014

Hwang, G.J., Lai, C.L., & Wang, S.Y. (2015). Seamless flipped learning: A mobile technology-enhanced flipped classroom with effective learning strategies. *Journal of Computers in Education*, 2(4), 449-473. https://doi.org/10.1007/s40692-015-0043-0

IB Curriculum (2020). *Curriculum*. Available at: https://www.ibo.org/programmes/middle-years-programme/curriculum/

Ideasfirst (2021). Available at: https://www.ideasfirst.net/what-we-do/ideas-hothouse-workshops

Lander, J. (2016). *Students as Teachers: Exploring the mutual benefits of peer-to-peer teaching – and strategies to encourage it*. Available at: https://www.gse.harvard.edu/uk/blog/students-teachers

Luckin, R., Baines, E., Cukurova, M., & Holmes, W. (2017). *Solved! Making the case for collaborative problem-solving NESTA*. Available at: https://www.nesta.org.uk/report/solved-making-the-case-for-collaborative-problem-solving/

Miller, B. (2016). *7 Pros and Cons of Case Studies*. Available at: https://greengarageblog.org/7-pros-and-cons-of-case-studies

O'Shea, M., Frohlich Hougaard, K., McGrath, C., Grainger Clemson, H., Vrhovski, I., & Kozak, M. (2020). Supporting Key Competence Development: Learning approaches and environments in school education. Publications Office of the European Union.

OECD. (2018). *The Future of Education and Skills*. Available at: https://www.oecd.org/education/2030/E2030%20Position%20Paper%20(05.04.2018).pdf

Perry, B.D., & Ablon, J.S. (2019). CPS as a Neurodevelopmentally Sensitive and Trauma-Informed Approach. In Pollastri, A.R., Ablon, J.S., & Hone, M.J.G. (Eds.), *Collaborative Problem Solving* (15-31). Springer International Publishing. https://doi.org/10.1007/978-3-030-12630-8_2

Picard, R. (2004) Affective Learning - a manifesto. Available at: https://www.media.mit.edu/publications/affective-learning-a-manifesto-3/

Ricci. C. (2015). *Hothousing children is now the new normal but what are the consequences?* Available at: https://www.smh.com.au/education/hothousing-children-is-now-the-new-normal-but-what-are-the-consequences-20150610-ghl3vt.html

Rindaningsih, I., Findawati, Y., Hastuti, W., & Fahyuni, E. (2021). Synchronous and asynchronous with flipped learning Environment in Primary School. *PrimaryEdu: Journal of Primary Education,* 5(1). Available at: http://www.e-journal.stkipsiliwangi.ac.id/index.php/primaryedu/article/view/1883 https://doi.org/10.22460/pej.v5i1.1883

Rojas-Drummond, S., Mazón, N., Fernández, M., & Wegerif, R. (2006). Explicit reasoning, creativity and co-construction in primary school children's collaborative activities. *Thinking Skills and Creativity*, 1(2), 84-94. https://doi.org/10.1016/j.tsc.2006.06.001

Salmi, H., Thuneberg, H., Bogner, F.X., & Fenyvesi, K. (2021). Individual Creativity and Career Choices of Pre-teens in the Context of a Math-Art Learning Event. *Open Education Studies,* 3, 147-156. https://doi.org/10.1515/edu-2020-0147

STEAM Education for Teaching Professionalism (2020). STEAMTeach. European Commision Erasmus+ Programme (2020-1-ES01-KA201-082102). Available at: https://www.steamteach.unican.es/steamteach/

Szabó, T.P., Burnard, P., Harris, A., Fenyvesi, K., Soundararaj, G., & Kangasvieri, T. (2021). Multiple Creativities Put to Work for Creative Ecologies in Teacher Professional Learning: A Vision and Practice of Everyday Creativity. In Lemmetty, S., Collin, K., Glăveanu, V.P., & Forsman, P. (Eds.), *Creativity and Learning: Contexts, Processes and Support* (115-143). Palgrave Macmillan. https://doi.org/10.1007/978-3-030-77066-2_6

Thibaut, L., Knipprath, H., Dehaene, W., & Depaepe, F. (2019). Teachers' attitudes toward teaching integrated STEM: The impact of personal background characteristics and school context. *International Journal of Science and Mathematics Education*, 17(5), 987-1007. https://doi.org/10.1007/s10763-018-9898-7

TU Dublin Hothouse (2021). Available at: https://www.dit.ie/hothouse/industry/

Vine, E. (2020) *iSTEAMPLUS Flight project.* Unpublished manuscript. Hockerill Anglo-European College.

Weinhandl, R., Lavicza, Z., Houghton, T., & Hohenwarter, M. (2020). A look over students' shoulders when learning mathematics in home-schooling. *International Journal of Mathematical Education in Science and Technology.* https://doi.org/10.1080/0020739X.2021.1912423

Wiltschnig, S., Christensen, B.T., & Ball, L.J. (2013). Collaborative problem-solution co-evolution in creative design. *Design Studies*, 34(5), 515-542. https://doi.org/10.1016/j.destud.2013.01.002

Yin, R.K. (2012). *Case study methods.* In Cooper, H., Camic, P.M., Long, D.L., Panter, A.T., Rindskopf, D., & Sher, K.J. (Eds.), *APA handbook of research methods in psychology* (2). *Research designs: Quantitative, qualitative, neuropsychological, and biological* (141-155). American Psychological Association. https://doi.org/10.1037/13620-009

Published by OmniaScience (www.omniascience.com)

Journal of Technology and Science Education, 2022 (www.jotse.org)