A global capstone project course in the age of coronavirus pandemic: learning from the ME310 ReGlove case

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***Abstract*— Engineering educations deploy capstone courses as a way of supporting students' transition into the engineering profession. This paper presents a global collaborative product development project affected by several constraints due to the coronavirus pandemic in 2020. The paper analyses the students' journey, as they navigated the final part of the project, drawing on learnings for the coaching cohort to support projects with similar levels of autonomy. The analysis uses a hunter-gatherer model to analyze the journey of iterations in search of a meaningful problem to solve. By utilizing this type of tool the supporting cohort can maintain a dialogue about the journey towards a vision and having a foundation of when to nudge, when to push back, and when to refrain from involving in their work.**

***Index Terms*—Capstone course, Cohort, Design Thinking, Engineering education.**

I. Introduction

Engineering activities are often concerned with design and development of solutions to meet various human/societal needs. In engineering education, the CDIO-initiative [1] aims to ensure that graduates are both academically well-educated and at the same time have the individual skills to work in engineering teams in industry. In CDIO, one arena where engineering skills are trained and integrated with core theoretical knowledge is in projects. Higher education institutions deploy capstone courses as vehicles to train aspiring engineering designers for the complexities and challenges of working in the industry [2], asking them to work on problems situated in industry-relevant contexts of similar character that engineers would work on. These final-year projects contribute to several CDIO-syllabus areas and CDIO standards, including design-implement experiences, active learning, and integrated learning experiences [3]. In reviewing research on project-based learning, Dym et al. [2] conclude that project courses improve retention, student satisfaction, diversity, and student learning.

Recently it has been popular to move to a globalized perspective, where students are trained and coached in working in distributed collaboration with peers from other universities, places, and cultures around the world. Potential opportunities for teams include working around the clock (with seamless handoffs), tapping into diverse market cultures, and access to diversified expertise. Challenges include a shrinking window of opportunity for synchronous work due to time-zone differences, different work cultures, fewer opportunities for face-to-face communication and serendipitous meetings, all of which require more active management of the collaboration, including building trust within the virtual team [4].

The ME310 Global New Product Design Innovation master course at Stanford University [5] is a renowned engineering design capstone course, where a global cohort of students of design, engineering, and innovation, under leadership and supervision of academics and industrial practitioners embark on a year-long journey to address challenging real-world problems. Students are trained in human-centered design thinking principles to address wicked problems in distributed teamwork mode, progressing iteratively in divergent-convergent cycles of ideation, prototyping, and testing [2]. Industrial partners challenge students with project prompts, consisting of complex and ambiguous problems that require application of creative, analytical, and collaborative skills and abilities to develop and produce solutions.

ME310 was first run as a local capstone course at Stanford in 1967, allowing students to experience doing engineering design, with a pedagogy centered around problem-based learning [5]. The project challenges are approached using a design-thinking methodology that has been developed by the research team at the Center for Design Research at Stanford, using the course as a testbed for the research on design thinking. The course has therefore seen significant overhaul and changes over the years. From 2005 the course has adopted a global perspective on the composition of the design teams, pairing the Stanford student teams with international teams from globally dispersed universities to collaborate on a shared design problem [5]. The course has therefore served as a testbed for how to do design at distance, aided by digital tools for collaboration and knowledge sharing. Coaching by academia and industrial liaisons and coaches in collaboration, form an extended part of the global cohort [6].

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With the advent of better and more refined collaboration tools, aided by better connectivity, often right at your fingertips, the technology challenge of running the projects has been less of a concern, but it has been observed that challenges relating to effective collaboration and trust-building within the global team remains. Traditionally, teams travel for face-to-face meetings to address this aspect. Post-travel, collaboration usually improves, and for key activities in the projects, repeat-travel is warranted to facilitate decision making [6].

This paper is a retrospective of a global collaborative product development project which incurred several constraints to core design process learning activities due to the coronavirus pandemic in 2020. Co-located meetings were cancelled, and lockdowns posed adverse challenges for the team in decision-making and development of their final product.

Some terminology used in this paper is specific to the cohort's verbiage in communicating key elements of the process. Coaching, while sharing many aspects similar to teaching, coaches make it clear they do not have answers to the problem primarily serving to reinforce adherence to the design process. "The golden nugget" is an analogy refering to a unique problem insight having large potential upside value if solved. "killing your darlings" is alluding to the designer's ability to avoid a biased emotional connection to concepts allowing them to make lateral design rationale decisions.

The aim of the paper is to analyze and reflect upon the journey of the team and to discuss lessons learned from the augmented process in terms of how to potentially replicate the aspects deemed to have positively impacted the students' experiential learning in future projects.

The purpose of this paper is to scrutize the project outcomes and activities, in particular, the convergence phase of the project that took place under the cloud of the pandemic, making collaboration as well as decision-making challenging.

II. Method

This paper reports on a qualitative investigation and analysis of one such project where five students in mechanical engineering from Blekinge Institute of Technology collaborated with a team of four students from Stanford University. The project took place in the academic year 2019/20 when collaboration was substantially affected by the coronavirus pandemic. Sources include a semi-structured group interview and the documentation from the project, where decisions and priorities are traced. Further, the authors were part of the support team, so observations and reflections are captured. The interview was videotaped and notes consisting of selected transcripts was captured, which are presented in quotes translated from Swedish here in the paper.

III. Theoretical concepts

The foundational approach to engineering design in this course is design thinking, which is applied in a problem-based learning environment where the students are presented with a wicked problem that they first need to make sense of by applying an empathic mindset for their users to define the problems more definitively. It is not at all uncommon that this is done in an iterative manner, because the true answer must come from the process itself and their analysis and judgment of the work that they produce.

The process is ideally considered to follow an iterative loop, as presented in fig 1a (left), whereas the experience (especially for a well-performing team) feels somewhat more chaotic (see fig 1b, right) at first glance. Instead of following the loop in a mechanistic fashion, the team is more responsive to the findings from various activities.

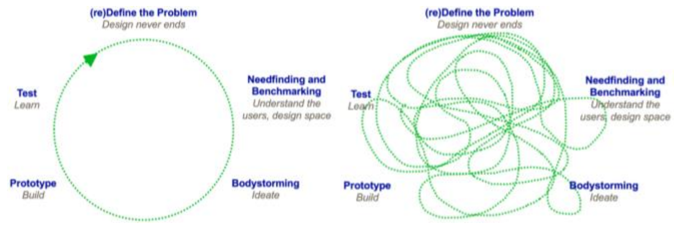

Fig. 1. The presented cyclical iterations vs the adaptively driven instantiation of the process (from [7]).

From a pedagogical perspective, the problem-based learning we are working with is closely aligned to the somewhat diffuse concept of thresholds [8], whereby forcing students to overcome troublesome hurdles of knowledge that we are trying, by means of coaching, nudging, and other means of instruction, to help the students climb across. Although the essence of group work is student–student interaction, the initiating, orchestrating, and managing of many kinds of group need to be performed by teachers [9].

A. *Design Thinking*

Traditional engineering is a relatively convergent process from a set of requirements via design concepts and specifications to realize products in an effective way [2]. When the problem is wicked there is a need for an approach that builds in tolerance for ambiguity and uncertainty, allowing for iterative exploration of the design space. Design thinking as defined by Brown (2008) [10] is a human-centered approach to innovation that draws from the designer's toolkit to integrate the needs of people, the possibilities of technology, and the requirements for business success. Design thinking serves as a framework to explore early design phase ambiguity while building empathy between internal and external stakeholders.

B. *Project-based learning*

As a way of motivating students for learning, one way is for teachers to integrate the doing with the learning in project-based scenarios to instruction that are problem-focused and meaningful for the trade of training that also integrate more fields of study [11].

Learning as a social activity, where project-based learning is an opportunity for students to train collaboration in teams as well as communication [2], supported by a design thinking approach.

Learning in project-based learning can be seen to follow three parallel and simultaneously occurring loops [12] (see fig 2); where the first loop deals with explicit knowledge that can be managed and collected in formal processes and data warehouses. Loop two is less formal, where learning occurs in interactions beween team members and their coaches, who assume tacit roles to facilitate formal expectations and actual team processes [12]. Learning loop three concerns tacit knowledge buildup by and within the team itself. With shared experiences and reflection, they can figure out ways forward and climb teir metaphorical thresholds. The learning loop belongs to the team, but a coach can be on hand to instill confidence in their abilities to keep calm and carry on in times of unease, essentially trusting the process and their abilities [12].

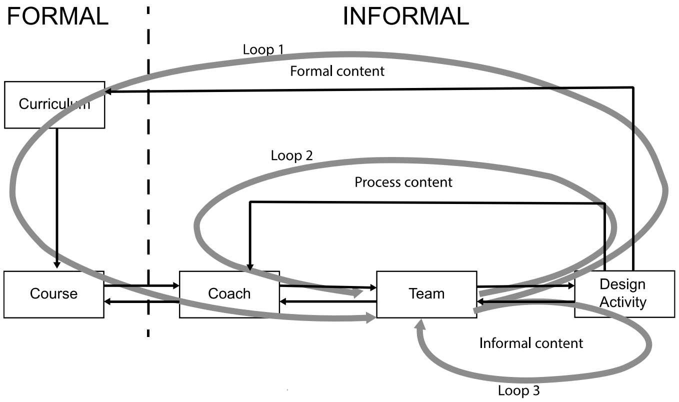

Fig 2. Triple loop learning (reproduced from from [12].

ME310 is based on the hunter-gatherer approach (see fig 3) to innovation [12], where the teams alternate between being hunters and gatherers meaning that they search for and implement what is the next big idea, the "golden nugget". With the hunter-gatherer model, even though an initial target outcome is set out, students should be aware that they are not working with a fixed target from day 1 that will persist. The initial target will only be valid for as long as until the first intervention, which is likely at one of the first iterations. Then the target and assumptions will be adjusted, which will be the case at each iteration. Gradually the team will hone in on a clearer target and hence they will work more towards bringing their solution to reality. Key to this is that the team is observant on development and willing to make interventions and adjust as is needed from their findings and reflections.

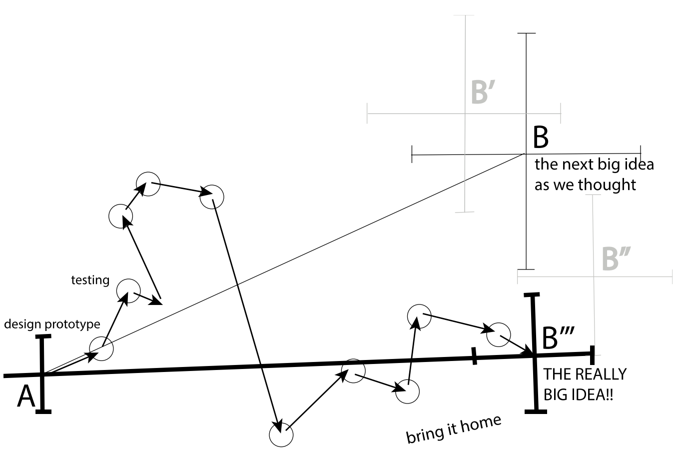

Fig. 3. Hunter-Gatherer model of a project with prototypes and tests to direct the progression through the process (reproduced from [12]).

Part of a design thinking process is its iterative nature, where new learning takes place as it is executed and where small adjustments and more substantive changes, also known as pivots (the term is prominent in the closely related topic Lean Startup) are decided because of the ongoing learning and customer feedback [13]. With a pivot, old hypotheses are discarded for new ones. Part of the ethos is to, as soon as possible, expose the ideas and concepts to relevant scrutiny so decisions about adjustments or cancellations are not postponed unnecessarily long.

Lande and Leifer (2009) [14] introduce a "ways of thinking framework" (see fig 4), comprising of four different modes of thinking in relation to the product development process, starting from future thinking, design thinking, engineering thinking and ultimately through production thinking. Although seemingly linear, it is on the contrary depicted as part of an iterative or spiral process approach to design. The future thinking focus resetting the problem and coming up with new questions, design thinking focuses on addressing and solving the problem, engineering thinking results in an artifact and ultimately production thinking is about addressing the manufacturing process. The application of the model from their work shows that benefits to outcome and learning experience comes from having repeated iterations between design and engineering thinking, but also that the teams touch on future thinking to reset the problem and questions to work from [14].

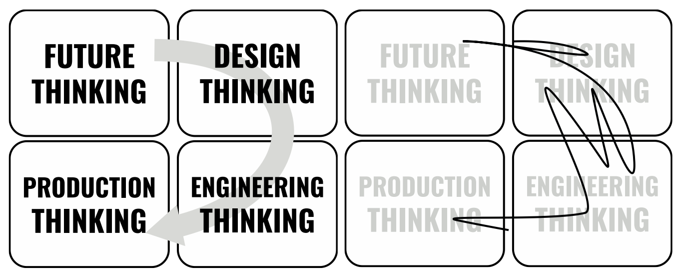

Fig. 4. Ways of thinking framework, illustrating the cyclical and iterative character of how design projects with uncertainty might look (reproduced from [14]).

IV. The 2020 BTH/Stanford project – arriving at ReGlove

The prompt from the partner, was wide asking the students to explore "the future of the waste industry", with the addition of the company's vision of eliminating accidents, emissions, and process stops. Initially, the team started exploring the problem space, going on "ride-along:s" in garbage trucks, observing users and existing solutions in the field.

Student 2 says, *"That was the most difficult bit; when it is so wide, it is difficult to find an area focus. We got started in the Waste industry, we went on ride-along:s with garbage trucks."*

A. Early prototypes to explore the problem space

Their learnings are always captured as tangible instantiations in various forms, allowing the students to communicate their findings and explore their lessons learnt in a collaborative way. The early prototypes related to recycling plastic as 3D-printing filament, and applying A.I. to assist recycling by the curb. Eventually, they made a motorized trash trolley to address curb-side recycling. At the same time, the students worked on getting the team to gel in a good way and to build trust between them. Working together from the beginning is important, but the team also met face to face early in Stanford at the end of November 2019. From a coaching perspective, it is essential, from the beginning, to drive the students to form one team (not two subteams), as collaboration on distance is otherwise difficult, with sub-teams pull in different directions.

Student 3 says, *"We put a lot of focus early on to really get to know the American students. When we arrived there, we had a great time and we spent effort to have fun together. We were there to learn more about how they think about things, but also to have fun together."*

Student 2 says, *"Without that kickoff week we wouldn't have any collaboration at all. Just a few meetings here and there."*

Further trips are planned for mid-spring, when the US team goes to Sweden, and the end of the project, when they all meet up at Stanford for final assembly and product launch.

Student 2 says, *"Later in the project we could have seen a lot more frustrations when you don't get it your way. But since we had this experience, it was a lot easier to listen to one another and respect the different views. That was very important. With good team spirit, it is a lot smoother."*

Student 1 says, *"And that we were one team, then you cannot compete with each other."*

During the first visit the teams produced an initial concept based on early shallow needinging of a trolly to automate garbage bin gathering called "The Trolley". Feedback provided about the trolley concept in coaching emphasized reflection on the "golden nugget"-level insight the process intends the students to hunt for. The trolley was deemed to lack a uniqueness and depth of needs to justify a final solution. Even though they feel frustration, the coach's role is to challenge them to "kill their darling" and continue the hunt for new targets, with new concepts and prototypes.

B. Further exploring the solution space

They now turned to plastic recycling and packaging at industrial scale, discovering a polyvinyl alcohol (PVA) from which to address packaging waste streams, by making them water-soluble so that people would rinse them in the sink.

Going forward from this point into the next quarter, having identified the need for more needfinding and benchmarking, the students moved on from their fall convergence and kept exploring more needs and solution concepts.

Student 2 says, *"It was a challenge to structure the work; which areas should we begin with, how do we divide the work and when do we know that we have done enough? Should we go on or just put it on hold?"*

Student 1 says, *"It was a long period with uncertainty, which was probably the point."*

As a coach, it is important to maintain and instill trust in the process, that not settling for less and keeping going exploring will eventually wash up something good.

The prototyping at this stage was challenging, struggling to make the They were in the middle of the "groan zone" [15], where intensified interaction and exploration of the wicked problem is needed.

Although being audacious, rinsing large amounts of PVA-packaging material did not gel in terms of circularity and sustainability, which is an important target for the project.

Also at this point, the coronavirus started to spread and the face-to-face convergence meeting in Sweden was cancelled with short notice. This move initially sprung some frustrations, feeling at risk of delay with convergence on a solution that potentially was not their true "golden nugget". From a coaching perspective, it was key to push back with questions and keep students focused on their hunt for vision and satisfaction of needs, despite the restrictive external factors out of their control. Swiftly they realized that they had to work out both convergence and collaboration because the externalities of the situation were not changing.

C. The pivot to Personal protective equipmen (PPE)

With the coronavirus came also the eureka moment. One student was walking his dog and noticed personal protective equipment thrown at the curb .

They started to discuss whether they could "pivot" and use their material to create a circular supply of remanufactured protective gloves. They set about doing research and then realized that there is potential to address the issue and thus changed tracks. With the pandemic, they found a sense of urgency to address a real challenge in society and an opportunity to disrupt this space.

Student 1 says, *"Selecting this topic, which was directed towards a major problem in the wake of Covid-19 we also felt an urgency not just for our studies, but also to deliver a solution that provide a result."*

With this pressing problem and eureka moment, the students got wind of an opportunity, but still needed to do their due diligence once again. Here research had to be made both into the feasibility of the solution as well as the desirability and viability from the healthcare system. The students relatively quickly got an understanding of both shortages of PPEs as well as the volumes of single-use PPEs on a normal year, both indicating that this is a problem that is interesting to look further into and explore opportunities to disrupt the way things are done in this space.

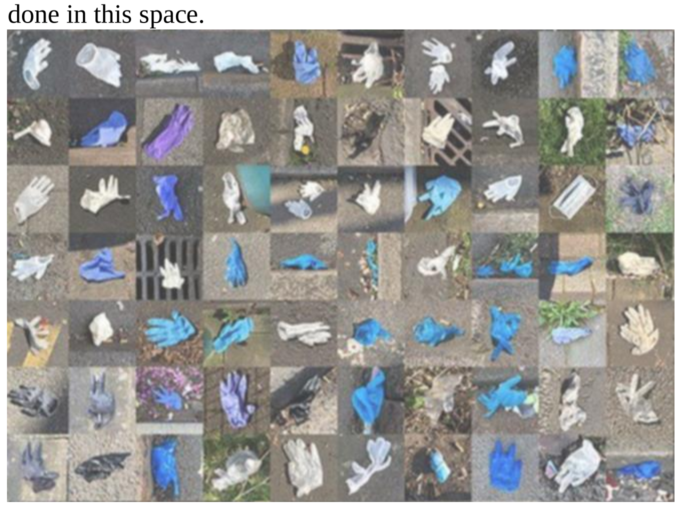

Fig 5. Illustrating the need of addressing the PPE-recyclability problem.

D. The Reglove system development

They developed a circular concept of a popup remanufacturing plant for sterilization and remanufacturing of single-use gloves.

They set about proving all steps of the chain, quite often using kitchen supplies as their regular prototyping facilities were closed. They finally built a remanufacturing molding unit (see fig 6) to prove that the gloves could be made from recycled PVA.

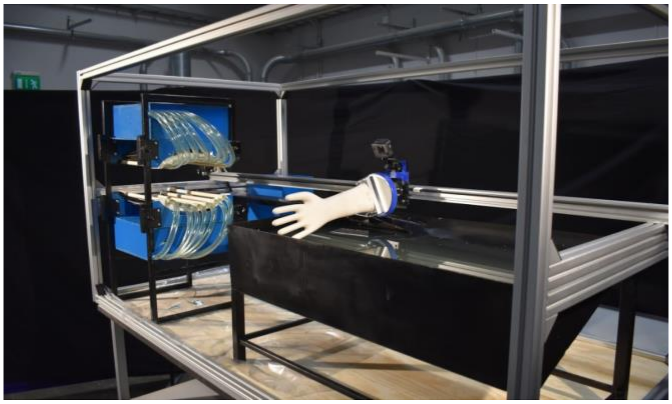

Fig 6. ReGlove molding unit.

The solution that came out from the accelerated development process was a process (see fig 7) for achieving a better circularity from, where each component is on piece of the pie to achieve a circular system from remanufacturing of single use PPEs. The molding unit in fig

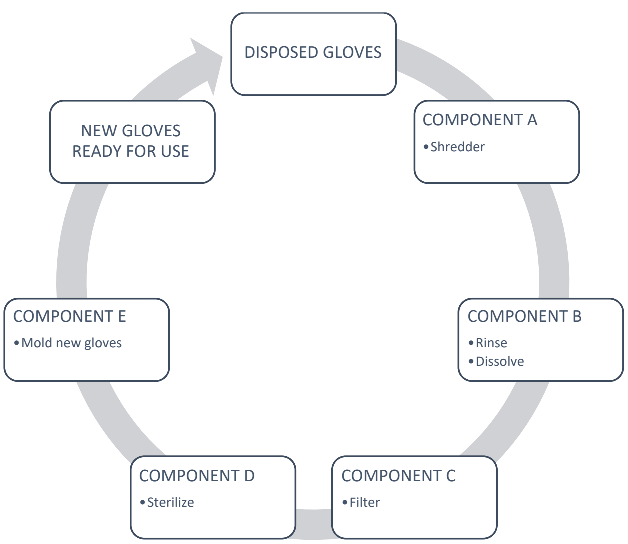

Fig 7. ReGlove circular remanufacturing process.

Student 1 says, *"We have created PPE gloves from a water-soluble plastic. The idea is to show that we can produce gloves that can be used as single use PPE gloves. Since it is water-soluble, we can also recycle it. […] In this way we can achieve a circularity for these kinds of materials, which otherwise would have been thrown away or being burnt in a waste management facility. […] We have built a proof of our concept, which is much larger than this machine. We create circular flows for single-use materials. […] To take the whole circle around, we are cutting a waste stream, so it is well within the prompt."*

In the final little more than one month, of a project running for about eight months, the students went about proving all steps of a circular remanunfacturing chain, from cleaning and sterilization to remanufacturing is proven by prototypes and lab-scale tests. This goes to show that with the "right" problem, some sense of urgency and meaning, the challenge of feeling the stress can be managed – they had found their "golden nugget". As a coach, this shows the importance also for us to trust the process, pushing back when the students crave for certainty.

The mechanical performance of gloves that had gone through six iterations of remanufacturing was still considered sufficient, meaning that up to 83% waste can potentially be saved with the process [16].

Student 1 says, "It will reduce both material transports from far away factories and transports from the hospitals to incineration of contaminated materials."

Student 3 says, *"Relying on making gloves on the other side of the planet when we cannot get it here, it is better to have the capability in-house.*

V. The hunter-gatherer for the ReGlove project

Illustrating the timeline of the project using the hunter-gatherer model [12] as earlier presented in the theory section, we can see that the team went about searching for different needs and visions through the project (see fig 8). The students started out making sense of the challenge by finding users and applications quite close to their daily lives that they could acquire and gather information from. Hence, the early visions also sidestepped the original prompt by focusing on more residential- and curb-side recycling challenges. We in the supporting cohort were aware of this and refrained from micro-managing the team and instead challenged them to keep hunting for their golden nugget. As each iteration was passed through and more learnings acquired, the targets and vision shifted for the next one, eventually finding the material that could form a foundation for a circular solution. The hunt was still on for an opportunity and a need, which came big time with theh Covid-19 pandemic. Here the "pivot" came about and the students started working out the process and soltutions that came to be ReGlove.

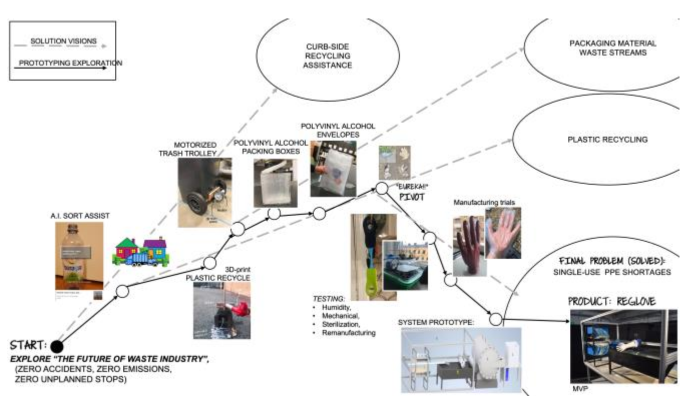

Fig 8. The hunter-gatherer map for the ReGlove project.

VI. DISCUSSION

By following the rapid path of prototyping this project serves as a representative example of two things; by pushing as many concepts as possible to a crude or audacious build phase they were able to gain invaluable insights into both the problem space and the solution space of which many subcomponents are visible in the final solution. Learnings born from failures were harder to accept for the team not accustomed to viewing failure as a positive, but through concerted nudging effort and maintaining original expectations regardless of the pandemic by the coaching team the team's stress was converted into a higher-than-average drive to succeed.

The Hunter-gatherer model that was adopted and used as part of the analysis of the team's journey holds promise to be a model for the supporting cohort in their facilitation of the team's process in their third learning loop. By having a shared vision of where to the team seem to be going, liaisons and coaches can keep a back office dialogue about when certain nudges and challenges might be needed. Sometimes, more steadfast coaching about the team's inclination to "kill their darlings" might also be needed, and with a shared view the team can support them in a coordinated manner, while maintaining an expectation of the team's own autonomy.

The pivot, requires courage to make when so little time remains, especially since it should come prefereably from the third learning loop. But knowing the global picture of the project could help in instrumenting and aligning the cohort to support them in making this tough decision.

What is particularly interesting with this project is also both the attention it has gotten and the continued development after the course has completed. The students filed an application for the 2020 James Dyson Award, finally being selected for the final round of the competition ranking top-20 out of more than 1800 entries. Thereafter, many industries and companies have observed what the students presented and shown interest in exploring their work further within their separate domains – effectively vindicating this tough choice that they made.

VII. CONCLUDING REMARKS

The aim of the paper was to analyze and reflect the journey of the global team and project that was affected by Covid-19 restrictions. The paper has presented the journey of the ReGlove project, which was initially a capstone project as any other with a global backdrop of team members being dispersed. At the beginning of the last period of the game, the conditions changed, and the opportunities for collaboration and plans was changed at short notice.

Lessons learnt from this experience is that not even in times of this much uncertainty, the cohort should deviate from "trusting the process", asking the students to keep hunting for their "golden nugget", and successively "killing off their previous darlings". With this type of situation, the urgency and motivation came naturally, which effectively gave a purpose to achieve impressive results in a short time frame. However, in a regular year, we should take inspiration from this in that it is valuable for quite long to push back and keep searching for that "golden nugget" – much longer than is comfortable.

VIII. ACKNOWLEDGEMENTS

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