A CHALLENGE BASED LEARNING COMMUNITY FOR HYDROGEN DEVELOPMENT AND APPLICATION

J.A.P. (Hans) Gelten, B.J. (Benno) Aalderink, R.P. (Richard) van Leeuwen

Department of Sustainable Energy Systems, Saxion University of Applied Sciences, M. H. Tromplaan 28, 7513 AB Enschede, The Netherlands

M.M.A. (Mirte) Disberg-van Geloven, S. (Stephan) Corporaal

Department of Human Capital, Saxion University of Applied Sciences, M. H. Tromplaan 28, 7513 AB Enschede, The Netherlands

Y. (Yashar) Hajimolana

Department of Thermal and Fluid Engineering, Faculty of Engineering Technology, University of Twente, Drienerlolaan 5, 7500 AE Enschede, The Netherlands

ABSTRACT

The University of Twente, Saxion University of Applied Sciences, ROC of Twente (vocational education), centre of expertise TechYourFuture and the H_2Hub Twente, in which various regional hydrogen interested corporations are involved, work together to shape a learning community (LC) for the development of innovative hydrogen technology. The cooperation between company employees, researchers and students provides a means to jointly work on solutions for real-life problems within the energy transition. This involves a cross-chain collaboration of technical programs, professorships and (field) experts, supported by human capital specialists. In the LC, a decentralized hydrogen production unit with storage of green hydrogen is designed and built. The main question for this research is: how can the design and construction process of an alkaline electrolyzer be arranged in a challenge based LC in which students, company employees (specialists) and researchers can learn, innovate, build-up knowledge and benefit?
In this project the concept of a LC is developed and implemented in collaboration with companies and knowledge institutions at different levels. The concrete steps are described below:

1. Joint session between Human Resource and Development (HRD) specialists and engineers / researchers to explore the important factors for a LC. The results of this session will be incorporated into a blueprint for the LC by the human capital specialists.
2. The project is carried out according to the agreements of the blueprint. The blueprint is continuously updated based on the periodic reflections and observed points for improvement.
3. Impact interviews and periodic reflection review the proceeding of the LC in this engineering process.

The first impact interview reveals that the concept of the LC is very beneficial for companies. It increases overall knowledge on hydrogen systems, promotes cooperation and connection with other companies and aids to their market proposition as well. Students get the opportunity to work in close contact with multiple company professionals and build up a network of their own. Also the cooperation with students from different disciplines broadens their view as a professional, something which is difficult to achieve in a mono-disciplinary project.

KEYWORDS

Hydrogen development, hydrogen applications, Learning Communities, engineering, standards: 2, 5, 6, 7, 8, 9

INTRODUCTION

Due to worldwide climate change caused by CO_2 emissions, there is an increasing urgency to change energy systems towards 100% renewable energy. Green hydrogen is a promising renewable energy carrier for transportation, industrial applications, building activities and heat demand. It is produced either from biobased sources or by electrolysis of water using electricity from renewable sources, e.g. next to large wind turbine or solar PV farms, or as part of local or regional energy hubs (Shiva Kumar *et al.*, 2022; Nguyen *et al.*, 2019).
The demand for engineers with electrolyzer and hydrogen know-how is increasing, so there is a need for hydrogen related training opportunities (Tretsiakova-McNally *et al.*, 2017). Learning Communities (LCs) have proven to be a suitable form of training (Corporaal *et al.*, 2021), and it may cover different engineering and societal aspects of hydrogen technology.
According to 'The future of hydrogen' (Gül *et al.*, 2019), it is expected that the creation of jobs in manufacturing, installation and maintenance of electrolyzer systems will be increasingly important worldwide. The importance of a potential vocational training based (e-)learning program is stressed, covering different types of fuel cells and applications and targeted mainly at safety, automotive and stationary fuel cells.
During the last 20 years, the Conceive, Design, Implement and Operate (CDIO) initiative has been focusing on bridging the gap between engineering education and the industry's vision for their new employees' skills. According to the CDIO, engineering education should focus on real-world demands in the complete value chain and all skills needed to successfully execute the engineering profession (Crawley *et al.*, 2007). Hence, the CDIO approach is largely based on the idea that students should, during their time at the university, face reality-alike contexts and situations that facilitate learning of professional skills which are very important to prepare students for their future profession. Simulating these settings can increase students' motivation and enhances learning.
The University of Twente, Saxion University of Applied Sciences, ROC of Twente (vocational education), centre of expertise TechYourFuture and the H_2Hub Twente work together to shape a challenge based LC, where a decentralized production unit with storage of green hydrogen is designed and built.

In section 2, a theoretical background of challenge based LCs is presented. The theory is used to develop a blueprint for the challenge based LC in the engineering project HYGENESYS (section 3). The first impact interview indicates that the LC is functioning well and the first conclusions that can be drawn, are presented in section 4 and 5 of this paper. The paper ends with section 6 by expressing some future lines of research.

SETTING UP AN EFFECTIVE LC

LCs are public-private partnerships in which learning, working and innovation merge into a hybrid learning environment. Although there is a great diversity of manifestations of LCs, a number of core dimensions can be specified (West *et al.*, 2017). A 'community' is seen as a group of people who interact with each other around a common issue or interest. Participants in a LC work together collectively on a meaningful challenge to build on already existing knowledge, and thus learn at the individual and group level (Blackshaw, 2010). The interaction between participants is promoted if, on the one hand, they feel interdependent and responsible for the problem, and on the other hand they feel safe and familiar in the group. The 'learning' in LCs is seen as a negotiation process between participants to increase knowledge and skills on a particular subject. Through knowledge sharing, critical and reflective surveys, collective and individual knowledge is increased (Stoll *et al.*, 2006). This 'learning' is necessary to be able to respond to rapid changes and to be proactive in innovation processes. In addition, learning, working and innovation are seen less and less as purely individual and isolated processes, but as a collaborative, co-creating and context-rich process in which these aspects come together. In this context, the quadruple helix is also referred to in which companies, knowledge institutions (students and researchers), governments and citizens play an (active) role in creating new knowledge, technologies, products and services (MacGregor *et al.*, 2010).

To make the proceedings of LCs visible at every level, the conceptual framework of 'value creation', developed by Wenger *et al.* (2011), is used. This framework has been applied in various sectors and lends itself well as a basis to provide insight into the great diversity of possible returns: immediate, potential, applied, realized and transformative returns. The stakeholders have their own motives to participate in these LCs. To tackle social issues and make optimal use of the up-to-date knowledge, skills, attitudes, expertise and talents of the individual participants, each of these stakeholders are important. Potential returns for these stakeholders can be described as follows:

Companies
Participation in LCs and the acquisition of new knowledge and skills that go with it, enables the introduction and implementation of innovative ideas, thereby improving the performance of an organization (Crook *et al.*, 2011). Participation in a LC not only leads to better trained employees; it can also contribute to the development of an organization's learning culture, which is an important predictor of innovative behavior and performance (Sung *et al.*, 2014). Furthermore, participation in a LC also increases cross-boundary cooperation, which can improve the competitive position of that company.

Knowledge institutes
Learning environments that are co-created by both educational institutions and companies can become nodes in the sector and/or region (Zitter, 2021). The revenues of LCs for these educational and knowledge institutions are twofold. On the one hand, LCs contribute to the generation and unlocking of knowledge, or rather the effect on professional practice, education, professionalization and knowledge development. On the other hand, LCs offer students the opportunity to be educated closer to or together with companies. By working on complex problems with practice, students develop adaptive ability, self-management and collaboration; competences that are important in a changing world (Van Huffelen-de Boer, 2019). These authentic assignments motivates students, in accordance to Jaca *et al.* (CDIO, 2021).

Citizens
The role of civil society and citizens is especially valuable for strengthening social innovations in

regions. Social innovations can be defined as the development and implementation of new ideas (products, services, and models) to meet social needs and create new social relationships or collaborations. The role of civil society is crucial in addressing climate change and strengthening ecological innovations. Citizens as consumers are needed to represent the demand-side perspective of innovations. Civil society is an important stakeholder in regional innovation process and developments of innovations addressing sustainable development goals.

Government institutions

Governments have a great interest in solving complex social issues and for that reason governments subsidize projects that try to find solutions. LCs offer government agencies the space to look at solutions outside the usual systems (Schütz *et al.*, 2019).

In 2019, the Dutch national top sectors (*Topsectoren*) program joined forces in an action-oriented *Roadmap Human Capital 2020-2023* with the mission: 'a future-proof workforce as a condition for a flourishing economy and a positive social dynamic'. Part of the programming of this Roadmap is the weaving of LCs into the Multi-year Mission-driven Innovation Programs (MMIPs) of the top sectors and research programs of the Dutch Organization for Scientific Research (NWO). The concept of LCs is seen as the solution to connect learning, working and innovation. In the Roadmap, LCs are seen as an umbrella term for various forms of inter-organizational collaboration such as Living Labs, Field Labs, hybrid learning environments, professional workshops, innovation workshops and Centers of Expertise (Topsectoren, 2019).
LCs aim to contribute to solutions for major social or technological issues. To achieve this goal, proceedings must also be realized at underlying levels, such as revenues for organizations and individuals. To provide insight into this layering of revenues, a distinction, as shown in figure 1, is made between proceedings at micro level (individual returns), meso level (returns for organizations and knowledge institutions) and macro level (social returns) (Schipper *et al.*, 2022).

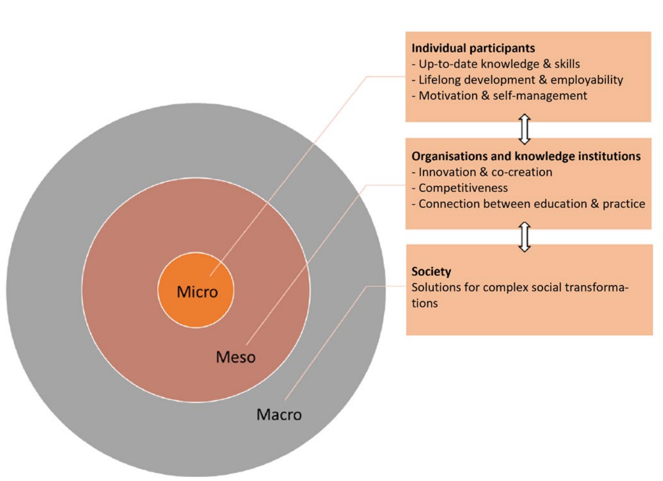

Figure 1. Schematic representation of LCs revenues at the micro, meso, and macro levels (Schipper *et al.*, 2022, p. 20)

The challenge based LC for the HYGENESYS project delivers revenues on micro, meso and macro scale for the involved organizations, educational and government institutions. The developed LC is based on some key elements as identified in a previous research project (Corporaal *et al.*, 2021):

- **Multidisciplinary work**: Learning within the LC is basically a social process, but is closely connected with individual learning. Individual stakeholders bring in their own expertise but there is a joined responsibility for the final deliverables. A facilitator supports the three most important aspects of team learning (team activity, team reflexivity, boundary crossing).

- **Shared ownership**: Learning and working is situated and integrated with daily social practice. The challenges are within the working domains of the stakeholders and results are directly relevant and applicable. Activities can be carried out within the chosen timescale.

- **Facilitating meetings between stakeholders, experts and students**: The LC fulfills the three main basic psychological needs for intrinsically motivated participants. These needs are connectedness, autonomy and self-management. Participants feel confidence (self-efficacy / team-efficacy) and competence, both through the support of the organization and through the facilitation offered. Learning, working and innovating within the LC is self-managing and agile. Scrum is the preferred methodology. The joint process is socially regulated, where the individual process is self-directed, possibly through co-regulation.

- **Organizing effective ways of knowledge sharing to bring the proceeds of LCs to society**: The LC focuses on making the learning outcomes more sustainable and continuing the LC itself. The LC results in a way-of-working (for instance sharing knowledge) and is integrated in following projects and co-operations.

Evidence-based research about work design, workplace learning, team learning, self-directed learning and motivation translate these key elements in design principles for the LC blueprint (Corporaal, 2019). In this project the development and construction of the electrolyzer (project HYGENESYS) is translated into a macro, meso and micro LC based on the mentioned design principles in which students, professionals and stakeholders work in teams together on challenges from the HYGENESYS project plan.

DEVELOPMENT OF THE CHALLENGE-BASED LC BLUEPRINT FOR THE HYGENESYS PROJECT

Currently, there is still limited knowledge available both in industry and at knowledge institutes about the realization and application of hydrogen production equipment at larger scale. The technological development of constructing a robust and safe hydrogen electrolyzer is a challenging multi-disciplinary engineering task. It consists of several steps, ranging from global system engineering towards drafting a detailed design, followed by manufacturing, testing and verification. This development is well written in the HYGENESYS projectplan, where all the work packages and challenges are described. These challenges are carried out by several companies and knowledge institutes within the LC. Figure 2 shows work package 2 (out of 5), the involved challenges and companies and the concept design of the LC.

The consortium of companies and knowledge institutes is a mix of specialists and generalists, each with different interests and ideas. In order to come to an operational electrolyzer system, the process was split into several manageable challenges, linked to specific companies, researchers and students that have the appropriate skill set to tackle the task. For work package 2 these (sub)challenges are shown in figure 2 (left), resulting in the design for the challenge based LC (right).

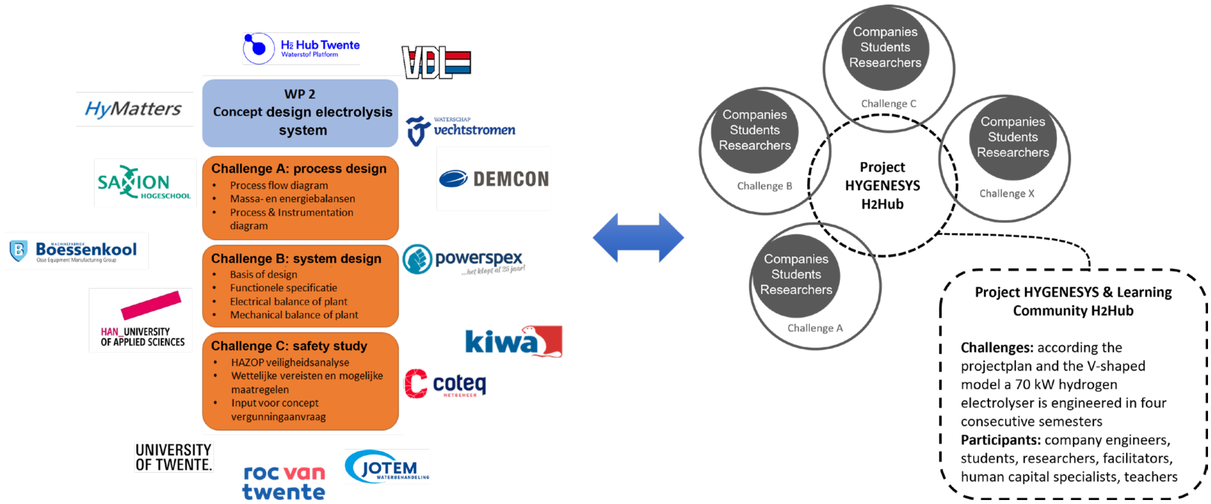

Figure 2. Work package 2 and consortium from the HYGENESYS project (left) versus concept design LC (right) (Corporaal *et al.*, 2021).

The main question for this research is: how can the design and construction process of an alkaline electrolyzer be arranged in a challenge based LC in which students, company employees (specialists) and researchers from the three educational institutions can learn, innovate, build-up knowledge and benefit?
An important aspect within this LC is to obtain commitment from all involved stakeholders and to formulate clear working agreements. This should lead to a situation where all partners benefit from the project. To accomplish this the following steps were taken:

1. Joint session between HRD specialists and engineers/researchers to explore the important factors for a LC. The results of this session will be incorporated into a blueprint for the LC by the human capital specialists.
2. The project is carried out according to the agreements of the blueprint. The blueprint is continuously updated based on the periodic reflections and observed points for improvement.
3. Impact interviews and periodic reflection review the proceeding of the LC in this engineering process.

The developed model for the LC that includes the key elements described in Section 2 is represented in figure 3, in which (multi- or interdisciplinary) LC teams, learning paths of students and professionals and expertise platforms are connected. The LC teams work in an equal collaboration on integrated complex issues and consist of multiple stakeholders, in which the field of work, education and research are always represented.

The concrete steps towards the LC blueprint for the HYGENESYS project are described below:

1. Participating companies from the project HYGENESYS are approached for a LC design session. In this session, HRD specialists and engineers/researchers have an open discussion to retrieve how the business community views the development and how knowledge institutes involve students and researchers in the process. Each involved participant is given the opportunity to express their view on the way of cooperation within the LC. The results of the design session is incorporated into a blueprint for the LC by human capital specialists.

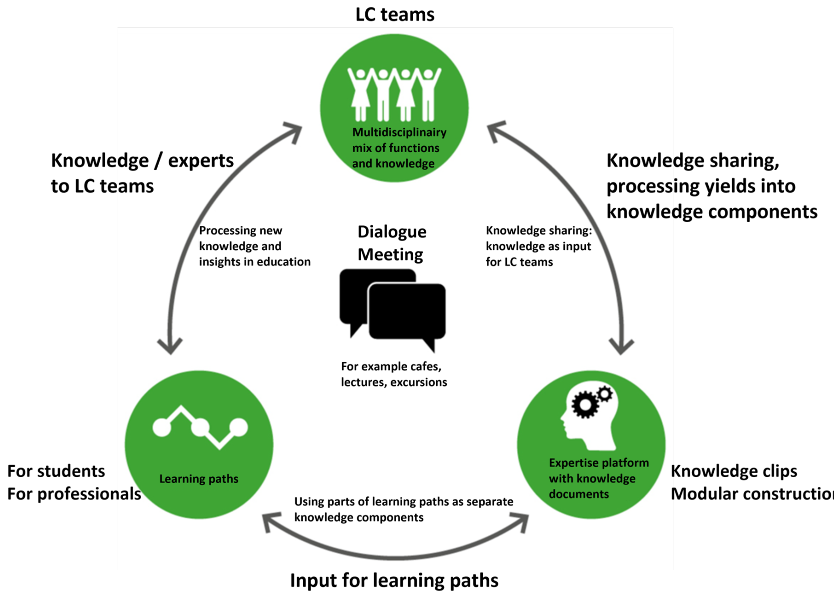

Figure 3. Model for developing the LC for the HYGENESYS project; the purpose and deliverables of a LC (van der Laan *et al.*, 2022)

2. During the kick-off of the HYGENESYS project, the main goal is to form the LC for the challenges, make work agreements and streamline expectations. The most important indicated attention points are project focus, concrete results or output and ways of communication.

Based upon the design principles, the development session with stakeholders and the kick-off meeting, the concrete blueprint for the challenge based LC for the HYGENESYS project was developed. Table 1 shows this blueprint and summarizes the ideal settings for the most important parts.

Table 1: blueprint for the HYGENESYS LC

Part	**Elaboration**
Challenges central	The LC starts with two major challenges. Divide big challenges into smaller parts (which are manageable, following the partial outcomes of each challenge). In addition, also organize plenary meetings (e.g. 4 times a year) to facilitate knowledge exchange between the challenges (all participants are present). Goal: small solutions contribute to the big challenges
Participants	Number of participants can vary per group of the (sub)LC, depending on the knowledge that is required; determined in advance. Starting from max 8-10 persons per LC.
Frequency of meetings	Per (partial) LC a period of 4-5 months to work (± 20 meetings), with a weekly or biweekly physical meeting of 3-4 hours. Goal: knowledge sharing and monitoring progress
(Learning) activities	In between the LC meetings, various activities take place; e.g. visits to different companies, suppliers or other places where H_2 is used. Or to test things at the test location.
Facilitator	Preferably someone who has no knowledge /experience with the subject; or in collaboration with a technical manager per challenge.
Consortium guidance	Internal and external communication, both technical target group and 'the ordinary person'. Time planning and all practical matters. Confidentiality versus openness

The blueprint is a starting point of the collaboration within the LC, but will be reviewed and improved during the course of the HYGENESYS project.

IMPACT AND PROGRESS OF THE LEARNING COMMUNITY

The project HYGENESYS and the challenge based LC started in September 2022 and will continue in four consecutive semesters till September 2024. In the first semester (September 2022 till February 2023) two challenges have started. Although the project is currently still in an early stage, the progress and especially the impact is already noticeable:

Figure 4. Progress and impact of the challenge based LC. *Left*: discussing work agreements per challenge during the kick-off, *middle*: the LC at work, *right*: sharing the progress and aligning challenges at a periodical consortium meeting

- **Kick-off HYGENESYS**: During the kick-off, the full consortium (students, companies and knowledge institutes) was present to discuss the blueprint and make working agreements suitable for the challenge involved (see figure 4, left). Coordinators of the challenges align the expectations of the stakeholders; students were introduced and specific agreements were made about planning and focus.
- **Challenges at work**: The two challenges (see figure 2) follow a rhythm suitable for the activities and deliverables. Challenge AB focusses on the global system design. Within this challenge, frequent meeting, discussion and knowledge sharing is necessary. The participants meet every Friday morning physically at the location of the H_2Hub in Almelo, The Netherlands for an intensive discussion and work session (see figure 4, middle). Each meeting starts with a scrum stand-up featuring the progress during the week, the planning for the coming week and questions or difficulties which were encountered. These short cycles of intervision enlarges involvement of the companies. Companies are encouraged to be present at these sessions and actively join the students in their work. The companies are involved via either junior or senior engineers and especially the junior employees gain knowledge and skills via this methodology.
  Challenge C deals with the safety aspects of the engineering process. These activities are much broader and will continue during almost the whole duration of the HYGENESYS project. Physical progress meetings are planned every month, are supervised by the coordinator and cover more work packages over a longer period of time. Safety and process engineering will eventually interact more strongly and meetings of both the AB and C challenges will be combined in the near future.
- **Periodical consortium meeting**: Every 10 weeks a plenary meeting is organized where the companies, knowledge institutions, students and LC coaches are invited at the H_2Hub location to discuss the results of the challenges and to consider the overall state of affairs within the project (see figure 4, right). This is also the opportunity to make strategical decisions in agreement with the whole consortium.

The impact that the challenge based LC already has, is recently evaluated during a first impact interview. During an open discussion, different stakeholders from the consortium reflected on the established LC. Table 2 shows the most important and striking remarks of the involved stakeholders from the different challenges.

Table 2: Impact interview for progress challenge based Learning Community

Stakeholder	**Impact**
4th year student Chemical Engineering	The concept to connect knowledge institutions, companies and students in this form, is new to me. Especially that you really operate and participate among the involved company specialists. To come in contact with so many different companies from different sectors is stimulating and would not have been possible otherwise.
Researcher University of Applied Science	In this LC there is an open attitude to share knowledge. There is a lot of exchange between the students and the structure makes students understand that their assignments are connected. This invites mutual sparring, an important learning process for students. In parallel to developing practical knowledge about hydrogen generation systems, this LC inspires to achieve research goals.
Associate professor University of Applied Science	In addition to working towards a final solution in a multidisciplinary group, the LC also brings a new focus to it: how do we learn from each other in this project? This equal cooperation aspect is already anchored to some extend in the Dutch working and consultation culture. The LC is an organically developing ecosystem with progressive insights that you cannot foresee in advance.
Senior Engineer company	The consortium ultimately develops an end-product together, and shares experiences to approach something like this from design and construction to the test and execution phase. The participating companies also learn from each other. Furthermore, expanding the company's network and taking a position on the labor market is important. If you are engaged in innovation, you run the risk of working in a cocoon. A LC gets you out of that. Weekly work sessions are a critical success factor and the trick is to celebrate our interim achievements with each other!
Chief Operational Officer company	The hydrogen market is still in its infancy and to achieve a viable market, a complete chain of production, storage, distribution and use has to be built. Everyone is needed to contribute to this, ranging from knowledge institutions and companies to students. As a company sharing knowledge externally in a LC to develop that market together, is necessary.
CEO H_2Hub and client	Working together with external partners is not new, but this collaboration based on a challenge-based LC is. In order to arrive at a prototype decentralized electrolysis system, developing knowledge together in many complex subfields is necessary. In the LC, the participating companies not only mix with, but also truly involve the students. That is what makes this LC unique. It is a kind of joint journey where the project sometimes has to turn left and sometimes right.
Project manager HYGENESYS	The challenge-based LC is a learning and innovation methodology in which researchers, students and company employees work together equally on (sub)issues in relation to the HYGENESYS project. Within this, they constantly inspire each other to innovate and create together. A research cloud environment is used with all relevant knowledge and data and is completely open to everyone who participates in the project. In addition, e-mail and practical WhatsApp groups for each challenge are used, which works very effectively.
Specialist Human Capital	In order to come to a solution, such as for this hydrogen application, a first step is the recognition of the need of both companies and knowledge institutions as well as that of students. It is a permanent learning process in which you support each other, question and help each other to move forward. In that way, all the prerequisites are met that belong to forming a community. As a result, the participants feel connected and involved. The core of a LC is that all participants are equal.

Note: the feedback in table 2 is all very positive. However, it is expected that it is still too early in the process to define any points for major improvements. These will probably emerge once a second batch of students goes to work. Then, difficulties related to knowledge transfer, planning and availability of students could be encountered.

There are several conclusions from the impact interview which are well in line with the design principles described in this article and the observations described in literature.

Firstly, the 4th year student stresses the importance of 'authentic assignments' and indicates that 'LCs offer students the opportunity to be educated closer to or together with practice'. The researcher from Saxion University of Applied Sciences notices that the 'students develop adaptive ability, self-management and collaboration'. This output of the interdisciplinary student-community is also observed by Mejtoft et al. (CDIO Conference, 2022).

Furthermore, the involved companies express the need to share knowledge and collaborate with other companies in order to make progress in hydrogen technology and development. Working within a LC 'increases cooperation across the boundaries of their own organization', while on the other hand joining the LC 'can improve the competitive position of the company'.

Thirdly, the LC gives results on micro, meso and macro scale:

- At micro scale motivation and management is highly self-regulated, there is build-up of open-access knowledge and '*lifelong development of company employees*'.
- At meso scale co-creation and connection between education and practice is clearly visible (for instance as mentioned by the CEO of the H_2Hub)
- At macro scale the development of a LC as organic ecosystem between students, companies and knowledge institutes in an equal work environment can be used for further initiatives in different fields.

Fourthly, the specialist around Human Capital observes that all prerequisites are met for having a successful LC, where the '*participants feel confidence (self efficacy / team efficacy) and competence*'. In the LC there is involvement, connectedness and equalness.

Lastly, working from a digital cloud environment and having both formal and informal contact between participants, leads to '*shared ownership*, where '*results are directly relevant and applicable*' for each partner within the consortium.

CONCLUSION

The energy transition requires new skills of people and for training of these skills, and the LC approach is a new concept where students work together with professionals on a real challenge. To set up a good working LC with mutual ownership between students, company specialists and researchers, theory and experience within this work conclude the following guidelines:

- Link challenges that are recognizable and attractive to all participants to the LC. A multidisciplinary and relevant project for companies is important, this ensures intrinsic motivation for all stakeholders.
- Create an equal substantive collaboration between the three participating stakeholders. This means that all participants learn from each other equally, the best condition for open cooperation.
- Create good knowledge transfer moments as participants in the LC gradually change and organize a stable and clear system for mutual communication and data storage in the LC.
- Physical contact moments to work with each other and consult around the project or challenges are essential for mutual involvement. These give motivation and energy to go further.

Although these guidelines work well within the presented engineering project and location, the authors would like to stress that setting up a LC needs also customization to the encountered situation.

FUTURE WORK AND CHALLENGES WITHIN THE LEARNING COMMUNITY

Future work will consists of a more elaborate evaluation and an applied science publication for similar situations to build up a LC for a technical project in the engineering domain.
The project HYGENESYS will continue on the development of the electrolyzer and the new work package 3 (from February till September 2023) involves a more specific and detailed engineering focus. Within the LC a few important aspects are faced:

- A new work package means new challenges within the LC. Coordination of these challenges is carried out by one of the consortium partners and will probably result in a change in work dynamics. It will take time and effort to deal with this new dynamics.
- The project HYGENESYS follows four consecutive semesters from the curricula of the students. Progress of the engineering development and the dynamics of the LC will strongly depend on the uncertain forming of a new group of (internship or graduation) students from different disciplines and/or knowledge levels. It is also a challenge to involve the vocational education, where the research focus is less important.
- It will take time and effort to arrange a good transfer between old and new students and for new students to get up to speed.

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REFERENCES

Blackshaw, T. Key concepts in community studies. Thousand Ouks (US): Sage; 2010.

Corporaal, S., Disberg-van Geloven, M., Endedijk, M., Hubers, M. D. (2021). Gas erop! Ontwerpprincipes van learning communities als aanjager voor de energietransitie. TechYourFuture.

Crawley, E. F., Malmqvist, J., Lucas, W. A., Brodeur, D. R. (2011). The CDIO syllabus v2.0. In Proceedings of the 7th international CDIO conference.

Crook, T. R., Todd, S. Y., Combs, J. G., Woehr, D. J., Ketchen, D. J. (z.d.). Does Human Capital Matter? A Meta-Analysis of the Relationship Between Human Capital and Firm Performance.

De Laat, M., Simons, R.-J. (z.d.). Collective learning: Theoretical perspectives and ways to support networked learning.

Eraut, M. (2000). Non-formal learning and tacit knowledge in professional work. British Journal of Educational Psychology, 70(1), 113–136.

Gül, T., Turk, D. (2019). The future of hydrogen, Seizing today’s opportunities. Report prepared by the IEA for the G20, Japan.

Honig, M. I., Ikemoto, G. S. (2008). Adaptive Assistance for Learning Improvement Efforts: The Case of the Institute for Learning. Peabody Journal of Education, 83(3), 328–363.

Hord, S. M. (2009). Professional learning communities. WHAT WORKS, 30(1).

Hülsheger, U. R., Anderson, N., Salgado, J. F. (2009). Team-level predictors of innovation at work: A comprehensive meta-analysis spanning three decades of research. Journal of Applied Psychology, 94(5), 1128–1145.

Jaca, C., Ormazabal, M., Arizmendi, M., Blanco, C. (2021). Project-based learning implementation - Collaboration between university and industry. In: Proceedings of the 17th CDIO International Conference, hosted online by Chulalongkorn University and Rajamangala University of Technology Thanyaburi, Bangkok, Thailand, 2021, p.137.

MacGregor, S. P., Marques-Gou, P., Simon-Villar, A. (2010). Gauging Readiness for the Quadruple Helix: A Study of 16 European Organizations.

Mejtoft, T., Cripps, H., Blocker, C. (2022). International professional skills: interdisciplinary project work. In: Proceedings of the 18th CDIO International Conference, hosted by Reykjavik University, Reykjavik, Iceland, 2022, p. 453

Nguyen, T., Abdin, Z., Holm, T., Mérida, W. (2019). Grid-connected hydrogen production via large-scale water electrolysis, Energy Conversion and Management, 200, p. 112.

Schipper, T., Vos, M., Wallner, C. (2022). Landelijk position paper Learning Communities (in opdracht van NWO). Zwolle: hogeschool Windesheim.

Shiva Kumar, S., Lim, H. (2022). An overview of water electrolysis technologies for green hydrogen production, Energy Reports 8, p. 13793.

Schütz, F. (2019). Co-shaping the Future in Quadruple Helix Innovation Systems: Uncovering Public Preferences toward Participatory Research and Innovation. 5(2).

Sung, S. Y., Choi, J. N. (2013). Do organizations spend wisely on employees? Effects of training and development investments on learning and innovation in organizations.

Tretsiakova-McNally, S., Maranne, E., Verbecke, F., Molkov, V. (2017). Mixed e-learning and virtual reality pedagogical approach for innovative hydrogen safety training of first responders, International Journal of Hydrogen Energy, 42, p. 7504.

Van der Laan, M., Moesker, H., Assies-Kroon, A. (z.d.). Learning Communities systeemintegratie. Rijksdienst voor Ondernemend Nederland.

Van Huffelen-de Boer, M., Van Sas, J., Endedijk, M. (2019). Aansluiting onderwijs-arbeidsmarkt: Leren en werken in de techniek en technologie. Enschede/Deventer: Tech Your Future

West, R. E., Williams, G. S. (2017). “I don’t think that word means what you think it means”: A proposed framework for defining learning communities. Educational Technology Research and Development, 65(6), 1569–1582.

Zitter, I. (z.d.). Leeromgevingen in het beroepsonderwijs als knooppunten in onze maatschappij. Lectoraat Beroepsonderwijs, Kenniscentrum Leren en Innoveren, Hogeschool Utrecht.

BIOGRAPHICAL INFORMATION

Hans Gelten is project manager in the research group Sustainable Energy Systems and responsible for the HYGENESYS project. He has a MSc. in chemical engineering with a special focus on hydrogen.

Mirte Disberg-van Geloven is specialist at the field of human resource development and works for TechYourFuture, centre of expertise. Her focus is the development of Learning Communities within the engineering domain.

Stephan Corporaal is professor Human Capital. He is involved in various applied research project about learning communities.

Benno Aalderink is associate professor Hydrogen Technology and Applications in the research group Sustainable Energy Systems. He is involved in the HYGENESYS project. He has a MSc. in applied physics and a PhD in mechanical engineering.

Richard van Leeuwen is professor Sustainable Energy Systems. He initiated the LC and HY-GENESYS project and is involved in several projects on system integration and smart grids.

Yashar Hajimolana is associate professor Energy Technology. His focus is the development of sustainable energy production through a range of fundamental research, modeling and characterization of fuel cell and electrolysis cell components.

Corresponding author

Hans Gelten
Saxion University of Applied Sciences
Dept. Sustainable Energy Systems
M. H. Tromplaan 28
7513 AB Enschede
The Netherlands
j.a.p.gelten@saxion.nl