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A week of real world challenge for biotechnology post-graduate students

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Abstract

Focus on sustainable processes and renewable raw materials, combined with rapid advancements in technology developments across scales, makes bio-based production processes a subject of great interest to both industry and academia. Despite this increasing prominence of bio-based production processes, there is a lack of a single course that can provide a thorough overview of the state-of-the-art industrial scale bio-based production, to early stage practitioners and researchers such as post-graduate students. BIOPRO World Talent Campus (WTC), initiated in the year 2013, was specifically designed and developed to address this shortcoming, and has thus far trained more than 120 post-graduate students from related yet diverse academic backgrounds from all across the globe. This manuscript describes the general and technical organisation of BIOPRO WTC and the unique academic and industrial collaboration that exists in Denmark which makes WTC a reality. A special focus is also placed on discussing a 48 hour industrial challenge that is set by leading Danish bio-based production companies and its impact on young post-graduate students, who get hands on experience in dealing with “real world” problems. Results from student surveys carried out during the five years of WTC are reported and discussed to understand the impact of the course. A future perspective is also presented with the focus on the possibility of employing emerging technologies to extend the outreach of the program.

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1 Introduction

Currently, there is a significant body of work as well as continuing research and development efforts within both academia and industry that are directed towards improving the process understanding of bio-based production. Collectively, these works are multi-dimensional across scales, multi-disciplinary and multi-sectoral in nature. For example, the development of accurate mathematical models for biogas production processes from the waste of bio-based production processes requires both laboratory and industrial scale information [1]. This type of work requires a collaborative academic and industrial effort which pools together knowledge, expertise and equipment. The BIOPRO strategic research centre was established to promote the collaboration, where large scale industrial partners work together with start-ups and universities in developing innovative industrially applicable solutions for improving bio-based production processes [2].

Starting from a set of renewable raw materials, the production of valuable final and intermediate products through chemical reactions and/or microbial fermentation in large scale production processes has been an area of interest to both academia and industry in the past decades [3,4]. Denmark has historically been a front runner in realising this trend, where companies have been employing bio-based production processes for production of bio-pharmaceuticals, food ingredients, biofuels as well as industrial enzymes [2]. However, despite a rapid growth, deep fundamental understanding of these types of processes is not as well established compared to many traditional chemical processes such as industrial chemical production.

From an educational point of view, covering the topic of industrial scale bio-based production processes can be complicated. Firstly, industrial scale bio-based production requires an individual or a project team to have multi-disciplinary knowledge encompassing the areas of chemical engineering [4], biochemical engineering, systems biology, process modelling [1], and process monitoring and control [5], as all of these areas are relevant and hot topics for ongoing research. As a result of the above factors, as well as the relatively novel nature of industrial-scale bio-based production processes, there is a lack of graduate-level reading material and courses that provide a good and thorough overview of the opportunities and challenges of bio-based production at an industrial scale. Indeed, of the eleven courses at the department of chemical and biochemical engineering at the Technical university of Denmark (DTU), only three are related to bio-based

production. Only one of these courses focusses on biological processes (bio-refineries), while the other two focus on aspects and innovation of different chemical and biochemical processes and are based on literature research. Multi-disciplinary areas have been an area of active interest in chemical engineering education. For example, a multi-disciplinary lab experiment for coke combustion in a fluidized bed has been designed to teach graduate students mass transport and reaction concepts [6]. Meanwhile, soft skills such as employability [7] or team work [8] as well as more technical concepts such as process safety [9] have also been of interest to educators in the area of chemical engineering.

From an educational perspective there is an urgent need for development of courses and/tools that can impart students with relevant applied knowledge as well as transferrable skills to adapt and excel in a rapidly evolving multi-disciplinary, inter-sectoral area of industrial biotechnology manufacturing

BIOPRO World Talent Campus, an intensive one week program, was developed to address these needs , with the following objectives 1) impart cutting edge, industrially relevant knowledge about industrial scale bio-based production processes; 2) build relevant soft skills of a select group of post-graduate level students from all over the world; and, 3) facilitate working in a multi-cultural and multi-disciplinary group.

In 2017, BIOPRO strategic research centre organized the 5th edition of WTC in Denmark, with 25 graduate students from universities across the world participating in this week-long course. The following factors make this course distinct from other similar modules in the area of biotechnology-based production:

- The course is a true collaborative effort between academia and industry with both sectors getting an opportunity to carry out lectures and presentations in an auditorium setting.
- The lectures are conducted by subject matter experts and cover a large range of relevant topics that are important in gaining a thorough understanding of challenges and opportunities in industrial scale bio-based production processes.
- The 48 hours industrial challenge is set by the industrial partners, where students work in groups on solutions to a real problem faced by an industrial partner.

- The course balances academic activities with extracurricular activities such as team building as well as showcasing Danish culture and lifestyle.
- It gives students a unique practical exposure to the bio-based industry which is extremely useful for those wishing to work in industry in the future.

As a result of these factors, WTC is currently the only course that allows graduate level students to get a thorough overview of the challenges of the industrial bio-based production industry.

In this manuscript we provide a comprehensive description of a unique multi-disciplinary, multi-dimensional and industrially relevant graduate level course, BIOPRO World Talent Campus (WTC) by reviewing and consolidating the outcomes of the latest WTC (2017) .as well as how they are allowing graduate students to get a thorough understanding of challenges and opportunities relevant for industrial bio-based production processes.

2 Campus Organisation Structure

The first edition of WTC was conducted in 2013 and since then, the organisational structure has remained the same. Figure 1 illustrates the overall organisational structure of WTC with the responsibilities of each partner listed. The BIOPRO strategic research centre, Technical University of Denmark (DTU), University of Copenhagen and Novo Nordisk A/S are involved in the major planning, administration and execution aspects of WTC. The industrial partners of the consortium: Novo Nordisk A/S, Chr. Hansen A/S, CP Kelco A/S, Novozymes A/S and Xellia Pharmaceuticals ApS are involved with the teaching modules of WTC, as well as outlining case studies and providing information for the 48 hours industrial process challenge.

Financial and administrative aspects are handled by the Process and Systems Engineering Centre (PROSYS), Department of Chemical and Biochemical Engineering, Technical University of Denmark. Neither the participant nor their universities incur any fees to partake in this course thanks to the generous donation by the Novo Nordisk foundation.

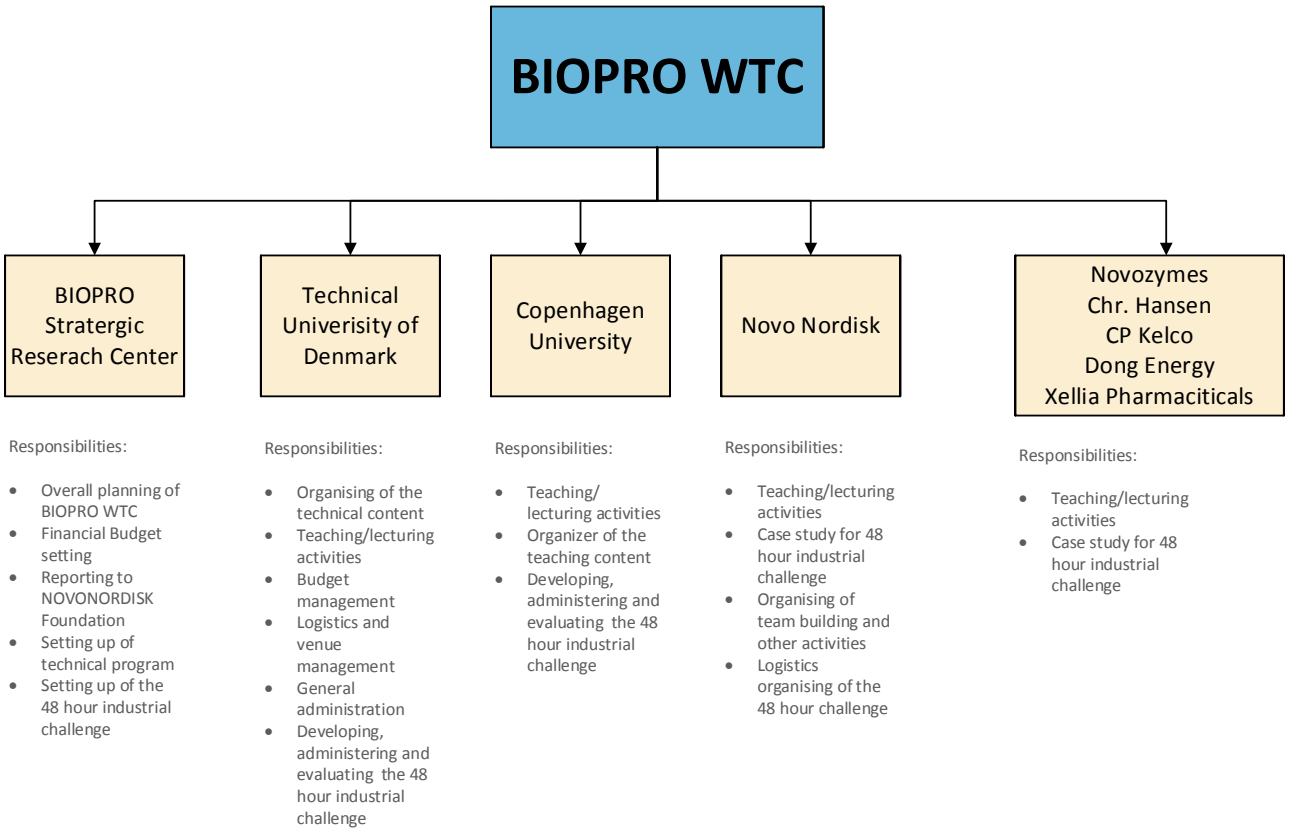

Figure 1: Organizational structure of BIOPRO WTC

The objective of the WTC is to achieve a good balance of technical content, while allowing participants, company representatives and organisers ample time to network. This allows participants to improve their knowledge base and build long lasting strategic relationships with their peers, the next generation of bio-based technology leaders. The course is conducted over a period of eight days in which the participants are either in lectures or solving industrial problems, as described in Table 1.

Table 1: BIOPRO WTC program

DAY 1	• **WELCOME TO DENMARK** • **INTRODUCTION TO THE BIOPRO WTC** • **SOCIAL ACTIVITIES**

DAY 2 - 4	• Lectures • Presentations by industrial partners • Team building activities
DAY 5-6	• 48 hour industrial process challenge (including company visits)
DAY 7	• Presentation of the results of the 48 hour challenge to the industrial partners and invited guests • Gala dinner with industrial partners and collaborators
DAY 8	• Visit to the Novo Nordisk Centre for Biosustainability • Tour of Copenhagen • Goodbye dinner

3 The participants

The participants for WTC are selected from a wide pool of applicants who are currently enrolled in graduate or post-graduate studies in areas related,to or of vital interest to improving the competitiveness of industrial bio-based production processes. In the past years, WTC has educated post-graduate students from over 20 universities. Figure 2 illustrates the universities represented in the 2017 edition.

Figure 2: Participant map of WTC 2017.

3.1 Selection criteria

Due to the generous funding that is provided by the Novo Nordisk foundation, the WTC course is held as a fully sponsored course, where all expenses (including air tickets) are paid for by the WTC for a select group of 25 students. Organisers of WTC look at the following factors when selecting participants:

- The applicants must be enrolled in post-graduate level studies in one of the key topics defined in the learning objectives (section 4.1)
- The applicants should demonstrate clear motivation and enthusiasm for participating in the WTC as well as expected learning outcomes.
- Applicants should identify thekey competencies that make them a valuable addition to the WTC
- The applicants should have a working proficiency in English and the ability to work in a group environment
- Being enrolled at a key research centre in the area of bio-based production processes will be a bonus.

In general BIOPRO receives a relatively large number of applications for each WTC, from which 25 successful applicants are selected. The selection process is carried out by a committee consisting of both academic and industrial partners of BIOPRO. Every application received is thoroughly reviewed by the committee, and the applicants are selected based on the collective agreement of the selection Committee.. The selection committee also strives to ensure there is a good gender and cultural balance amongst the selected participants.

4 Course Content

The WTC technical content/modules are developed and organised by PROSYS at DTU and the Department of Food Science at the University of Copenhagen in consultation with the BIOPRO strategic research centre, as mentioned in Figure 1. The course counts towards 3 ECTS (European Credit Transfer System) for participating post-graduate students.

4.1 Learning objectives

The WTC stands out compared to conventional courses as it effectively delivers its objectives and caters to the needs of a diverse set of participants with a variety of cross-disciplinary skills, capabilities as well as areas of interest. To this end, WTC will give participants a general overview of a topic, followed by an introduction to recent advances in the area. In WTC, the following topics are covered:

I. Introduction to bioprocess manufacturing
II. Process models and control of bio-based processes
III. Challenges in large scale bio-based processes
IV. Bio-based process design

At the end of the course the participants are expected to have a proficient understanding of each of these key aspects in the context of industrial bio-based production processes. The participants are also expected to be able to apply this information in solving real world problems and are given the opportunity to apply them during the 48 hour industrial challenge.

4.2 Technical program

The technical program of WTC 2017 is displayed in Table 2. In addition to the five main topics discussed in the learning objectives there are also presentations by the industrial partners, with a focus on current technologies routinely used in industry, as well as development of state of the art methods.

Table 2 Technical program of WTC 2017

Date	Lectures
Day 1	**Introduction to Bioprocess Manufacturing** 13.00 -14.00 Introduction to Process Analytical Technology/PAT 14.00 – 16.30 Downstream Processing 16.30 – 17.30 **Company 1 Presentation**
Day 2	**Introduction to Bioprocess Manufacturing** 9.00 -10.00 Process Analytical Chemistry/PAC **Process Models and Control** 10.00 – 11.00 Mechanistic Models, Parameter estimation and Link to Data 16.30 – 18.00 Basic Process Control, Introduction to Predictive Control **Large scale Challenges** 19.00 – 21.00 System Identification / Soft Sensors for Process Monitoring
Day 3	**Statistics for Bioprocesses** 9.00 – 11.00 PCA , PLS and Tensor models 11.00 -12.00 **Company Presentation 2** 14.00 – 15.30 (Multi-variate) Statistical Process Control/(M)SPC 15.30 -17.00 **BIOPRO Spin-out Presentations** 17.00 – 18.00 **Company Presentation 3** 19.00 - 20.00 **Company presentation 4**

The exceptional aspect of the WTC is that some of the participants themselves would be experts in at least one of these areas, and an open discussion is initiated by the lecturers, where the participants have a free and frank exchange of the challenges and opportunities in their area of expertise. In some instances, participants will engage in further discussion with each other as well as lecturers throughout coffee breaks sometimes well into the evening. These conversations have led to fruitful outcomes and collaborations. It is also important to note that, while these five topics do not cover all aspects of bio-based processes, they reflect the

key areas of industrially relevant and applicable research. They Furthermore they provide the participants with an overall picture of challenges and opportunities in bio-based production processes.

5 The 48 hour Industrial challenge

5.1 Learning objective

One of the most interesting aspects of the WTC is the 48 hours challenge, where the objective is to give the participants the opportunity to apply both the knowledge gained during the teaching activities as well as prior knowledge to solve real world problems faced by industrial bio-based manufactures. The 48 hour industrial challenge begins with dividing participants into groups, and presenting each group with a real-world industrial problem linked to an industrial partner that needs to be solved within 48 hours. Each group is selected so that there is a balance between participants with different backgrounds and skill sets. This requires the participants to interact with each other and combine their technical expertise to arrive at a single implementable solution.

5.2 How do the groups spend 48 hours?

At the beginning on the 48 hour industrial challenge each group is given a problem statement and the groups are given 3 hours to analyse the problem statement and come up with a hypothesis as well as points that need to be further clarified. The groups are the taken to visit the industrial partner aligned with the real-world problem. It is important to note that all industrial partners have restricted access facilities due to risks of contamination and confidentiality. However, the participants are allowed to tour these facilities after a safety introduction. For many participants this will be the first time they have visited an industrial scale biotechnological production process. The objective of the visits is for the participants to gain an intrinsic idea of the size and scale of the problems they will face in implementing a new concept/change in a facility, and take this into consideration when evaluating different scenarios for the generation of implementable and

practical solutions. The facility tour is followed by a detailed discussion on the challenge with the company representatives. The company representatives are experienced scientists and engineers, who impart practical knowledge to participants that help them in arriving at a practical solution. Following the visit to the industrial production facilities, the groups have roughly 36 hours left develop a best fit solution, taking into account all relevant considerations.

During the 48 hour industrial challenge, the candidates have to think out of the box and try to combine fine-tuned scientific solutions with practical industrial considerations such as cost benefit analysis, regulatory approvals, integration into existing production runs and plant layouts which contribute substantially to the decision making process. The challenge truly enriches the learning experience as participants within a group are from a multitude of backgrounds. The group discussion not only allows the application of specific scientific knowledge, but also allows for collaboration among disciplines. While initially some groups are challenged by this, most groups eventually manage to work out how to efficiently work as a team. The 48 hour industrial challenge is an excellent example of a team based learning opportunity, which is an area of active interest in chemical engineering education [8].

5.3 Learning outcome

At the end of the 48 hours, the participants are expected to present a short report documenting their findings as well as to provide a short presentation. The past solutions proposed to the 48 hours industrial challenge problems have generally been well received by the industrial partner companies. In some instances, these solutions have led to further detailed investigations into the topic and to the implementation of the suggested solutions. These success stories show that it's not only the participants who benefit from the case studies, but also the companies. As a result of the positive results gained during the 48 hours challenge, the industrial partners are continually encouraged to actively participate in this activity.

6 Student Experience

The feedback from the participants reflects that the lectures, company visits, and the 48 hours challenge are productive in terms of being state of the art, applied and industrially relevant. The social activities helped in

team building and networking. This can be gauged from the responses and questionnaire answers from former participants:

"It was one of the best experiences in a work environment for me. With well-planned lectures interspersed with social activities, it was a balanced one week. Rigorous and relaxing at the same time. Team building activities were fun and company visits were educating. It's always nice to meet peers from other universities. Biopro WTC gave me new friends who I learnt from and will cherish the one week in beautiful Sorø" states Sumana Narayana, a PhD student at University of Copenhagen, Denmark who attended WTC in 2017. The program promotes the motto of 'work hard, play hard' wherein several social activities are organized for the participants allowing them to interact with each other and aiding in the teambuilding. The balance described by Sumana finds common ground with the other participants, as evident from Figure 3a where 78 % of all WTC participants strongly agree with this observation, while another 20% agree. *"Biopro WTC was an extremely well organised course that started with mellow introduction in Copenhagen, continued with science camp in Sorø, peaked and intensified with the course project, and rounded off again in Copenhagen. The course was centred on biotechnology manufacturing and problems associated with large scale production. The lectures provide valuable material and insight into the subject, company presentations showed challenges the industry is facing and the course project allowed participants to provide their solutions for relevant problems"* states Andres Maser, PhD student at the Center of Food and Fermentation Technologies in Talinn (Estonia) who attended in 2017.

The majority of the participants (96%) would highly recommend this course to fellow students as evident from Figure 3a. In the past few years this was seen by the application of students who had heard from the course from previous participants and came with high expectations. As evident from Mathew Proctors, who comments *"Attending BIOPRO WTC improved my understanding of process analytical technology and, more generally, biotechnology, which has proven invaluable in my career. I also really enjoyed having the opportunity to network with world-leading experts and like-minded PhD students from all around the world."* Mathew attended the second edition in 2014, representing the University of Auckland, New Zealand. After completing his PhD, Mathew now works for a large dairy company in New Zealand.

One of the students that was referred to the course by a colleague is Noelia Gudino, PDEng student at the Technical University of Delft, the Netherlands, who attended in 2017: "*When looking for interesting courses to obtain a PDEng degree, a PhD colleague recommended me to apply for the BIOPRO course. She especially highlighted its industrial relevance. Indeed, I got to know several Danish companies, not only concerning their general activities but also about detailed technical aspects of their operations which I find very interesting. Additionally, I had the opportunity to significantly expand my professional network by meeting PhD candidates from all over the world involved in all aspects of biotechnology/bioprocess research. I found the BIOPRO course an amazing and unique opportunity to not only expand my technical knowledge but also to build new and valuable working relationships.*" While the course is just a week long, most feel that they have gotten a good orientation on full-scale processes, as for many it was the first time working on this scale. Due to the high diversity of participants in the course, it can be a challenge to tailor the lectures to the needs of those following it. As illustrated in Figure 3c, 63% of the participants strongly agree that they have gotten good theoretical knowledge of methods and challenges in full-scale bioprocess monitoring and optimization, while 32% agree within this statement. As such 95% of the students share a positive opinion on the theoretical content of the course.

As most of the participants are in different stages of their doctoral/master studies, WTC enables them to get an industry's perspective that is quite different from an academic one with respect to large-scale manufacturing. This included concepts such as process safety, which is much better illustrated and understood in an industrial setting [9]. The participants through the interactive group work also have an opportunity to improve their interpersonal and transferable skills which are increasingly become more important in chemical engineering education [10]. The lectures give a detailed insight into the scientific advancements made in the area of biotech manufacturing, namely bioprocess monitoring and control. Participants are given the opportunity to learn and network with representatives from the leading biotech companies as well as Universities, resulting in excellent exposure not only to the technical expertise and biotech manufacturing process they have to offer, but also to the hospitality and work culture that exists in Denmark. This networking is further promoted by the gala dinner organised at the Carlsberg Foundation

which allowes for a relaxed night of discussing the potential biotechnology advances that result from academia-industry collaboration. In the 2017 WTC, the attendees to the gala dinner also had the rare opportunity to tour the Carlsberg lab, which has been the birthplace of many innovations in fermentation technologies in the past century. All in all, the course puts Denmark on the map for academically educated talents from around the world. After the course, 73 % of the participants have responded that they see Denmark as a highly attractive environment to work in the biotech industry as evident from Figure 3d, while 22% also consider it as a good environment to pursue a further career.

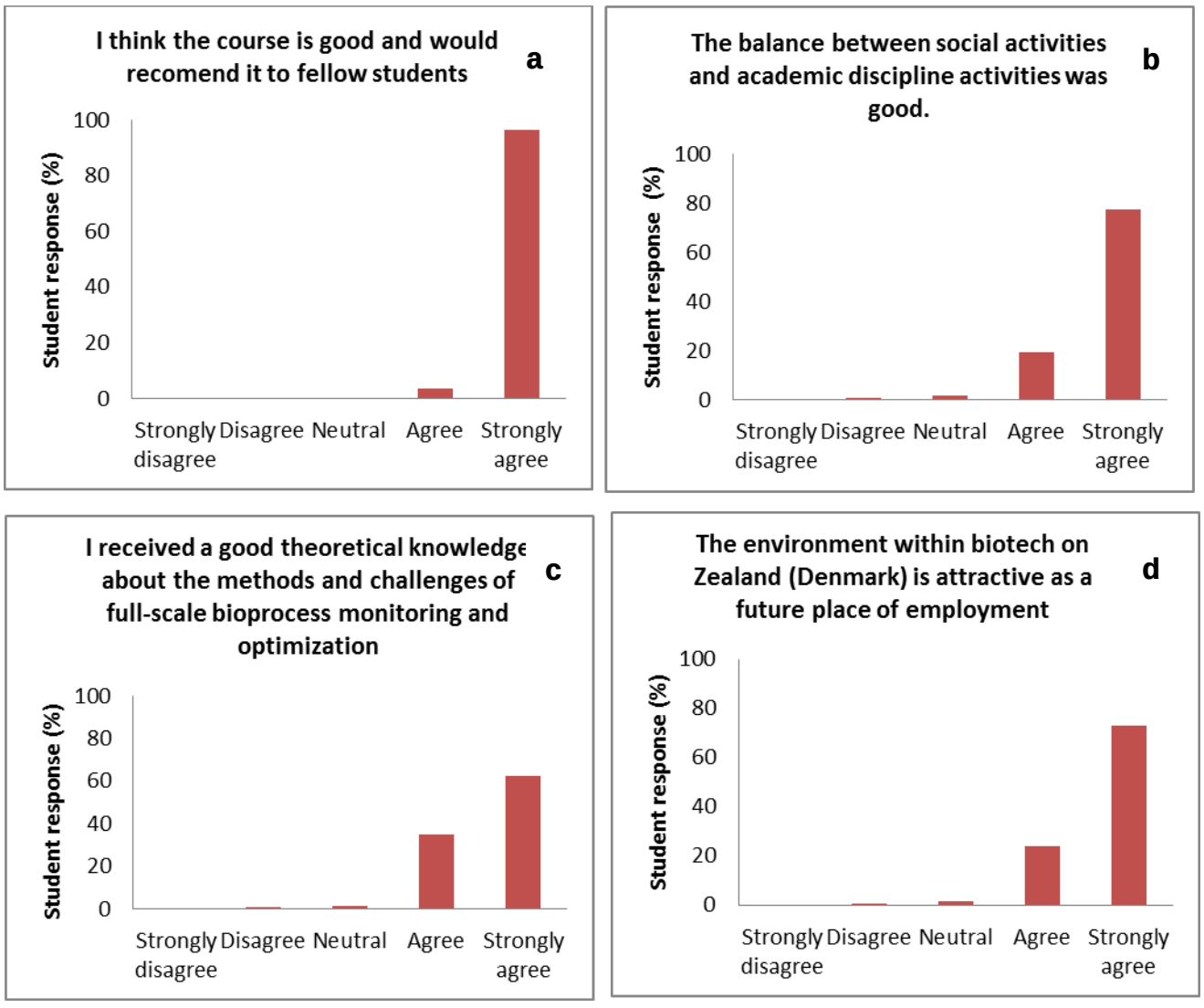

Figure 3: Results of highlighted responses to the questionnaire given to the participants after the course. The results are combined from the years 2013-2017 (120 participants).

6.1 Industry Feedback on 48 Hour Challenge

The industrial feedback to the solution proposed by teams at the 48 hour industrial challenge has also been overwhelmingly positive. This feedback has been made by the senior representatives of the industrial partners at BIOPRO consortium director board and steering committee meetings. For example one representative that has been involved with the 48 hour industrial challenge over the years remarked

In an industrial environment it is very difficult to get 48 hrs continuously to work on an issue. Getting the BIOPRO world talent team of 5 students is actually a perfect way to investigate on some of our challenges for which we do not have enough time, but are still very important to know why it happens. In 2015, 2016 and 2017 we have given industrial problems to the WTC participants, and they have suggested us solutions which are actually very relevant and useful to fix (these) issues. They put their heart out for these assignments and give their best to come up with logical solutions, as they might be getting a chance to come and work for us eventually. Though we are very busy in our daily production tasks it is completely worth spending time on these students and assignments as it is in our own interest as well.

This sentiment of mutually beneficial outcomes are shared by all the industrial partners involved, as over the last five years they have continued to dedicate their valuable time to represent their companies at the WTC lectures, as well as opening up their facilities and further allocating multiple specialists time during the 48 hour industrial challenge. It is also important to note that many of the solutions suggested over the years by the students have resulted in further studies and development, which in some instances has resulted in industrial implementation.

7 Extending Outreach

Although WTC has proved itself as an excellent opportunity for post-graduates to get relevant practical knowledge, network, and search for practical solutions to real problems faced by the bioprocess industry, the number of participants who can attend is limited by the funding and physical size constraints. As such, an

318 important number of young talents who apply for the course have to be turned down, which can be
319 considered a loss of opportunity.

320 One way to overcome the limitation of the number of participants, without affecting the high quality of the
321 course is through the creation of virtual labs [11] and even virtual classrooms [12], such as the online
322 certificated courses offered by prestigious universities, as well as virtual challenges, like hackathons. These
323 pedagogical methods enhanced by technology would allow the WTC concept to expand, without significant
324 ongoing financial commitment by the creation of an on-line exploratory platform to provide a close
325 experience in a large-scale plant, and with the possibility to connect people from different backgrounds. An
326 option to create an accurate representation is the implementation of the learning process on and around
327 spherical imagery of real operating plants, coupled with interactive embedded activities and content [13].
328 Although the use of virtual reality is a promising area in education and training, it is still in development,
329 with the improvement of the models used for the simulation or the technology required. Moreover, the
330 possibility to provide participants with an industrial experience through a virtual classroom has been
331 implemented in several companies such as Dow Chemical with its programs of "Interviewing Training" or
332 "Respect and Responsibility". The use of e-learning has been considered as a cost-saving measure, as it
333 avoids travel and classroom costs as well as time off-the-job. In the example of Dow Chemical, it was
334 estimated that a saving of $30 million was achieved in 2000 by the implementation of its e-learning web-
335 based system [14].

336 Although the use of virtual class room techniques has many important advantages, successful
337 implementation of the concept requires significant planning and effort. Even in an ideal environment, it is
338 not exempt from drawbacks. The most frequently mentioned drawback is the up-front cost, as it requires a
339 significant capital investment for design and implementation. On the other hand, the lack of interaction
340 among trainees can make the learning less attractive to the participants [15].However, this can be potentially
341 reduced by using tools such as chats/interactive environments and/or the creation of introductory videos of
342 participants. One concept that can be explored to remedy this issue is concepts such as gamification and
343 active learning, which has been an area of interest in chemical engineering education [16].

Another critical issue is the management of intellectual property rights (IPR), as it is an environment based on the close collaboration of several companies and universities. Therefore, a key difficulty in extending this type of a course through e-learning would be the legal aspects of separating private and public content. However, this can be overcome by proper knowledge and implementation of the intellectual property laws and protection mechanisms, such as copyright, patents, and trademarks. In the case of a virtual platform, it would be prudent for it to be protected by a copyright licence, where the copyright would provide control over the reproduction, distribution, performance, display of the work and the preparation of derivative works of all tangible media such as software [17].It is also important to highlight that copyright does not protect an idea, but only protects how ideas are expressed, and consequently will protect the participants and the company privacy.

Therefore, it is the authors' opinion that a virtual learning platform, with careful planning, design, and information technology infrastructure and change management, could provide the consortium the potential to expand global presence of its course. One potential path to avoiding the confidentiality and IP issues is the development of a benchmark bio-based production process, which has been a recent project that is underway at the Process and Systems Engineering group at DTU in conjunction with the BIOPRO consortium. The idea in this project is to develop a single benchmark simulation that captures all key features of bio-based production processes that are present in BIOPRO consortium companies, which can be used for education and testing purposes. Furthermore, the use of the new technologies, like virtual reality, leap motion, or immediate chat communication allows the creation of a global, accessible virtual class for the teaching of bioprocesses at an industrial scale level available to interested participants.

8 Conclusions

The lack of an advanced course in the area of bio-based production and the inherent multidisciplinary nature makes BIOPRO WTC a unique course. The WTC provides the participants with the opportunity to get a focused yet thorough overview of industrial bio-based production processes, while allowing them to apply the skills they have learnt during the course and previously on real world industrial problems. The student survey conducted as a part of the study illustrates that the overwhelming success of WTC is successfully

imparting technical and industrial knowledge to participants, while also providing a good balance between social and academic activities. WTC has also created a pool of alumni in the area of bio-based production with active ongoing collaborations. However, in the current format, WTC cannot accommodate a high number of participants; new technologies are being explored and this can pave the way to increase its future impact and outreach.

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