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Integrating bioinformatics in the teaching and redesign of the course *Applied Microbiology*

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Introduction

The emergence and rapid development of high-throughput DNA sequencing technologies has greatly impacted the biological sciences making many disciplines including microbiology more computationally intensive (Cummings & Temple, 2010; Macori et al., 2017). As a result, there is an increasing demand for researchers with skills in both lab-based techniques and bioinformatics (Mikheyev & Arora, 2015). Consequently, the successful incorporation of bioinformatics into wet-lab study lines is critical.

The Master level course *Applied Microbiology* is a popular course that receives good evaluations year to year. However, the bioinformatics-based theme "microbial genomics" recurrently poses a challenge to students. The objective of this paper is to provide an in-depth analysis of the current course with a focus on how to integrate bioinformatics. The reflection and analysis provided here will serve as a white paper for the revision and long-term redesign of the course.

Methods

Data from the course student evaluations from 2016 to 2019 was collected and analysed using the *Experiences of Teaching and Learning Questionnaire* (ETLQ) adapted from Enwistle et al., 2003. Course constructive alignment and congruence based on analysis of the student and course perspectives was performed using the Biggs and Tang, 2007 principle and further supplemented by student and teacher interviews to determine the specific challenges associated with the microbial genomics theme. Concept mapping was performed to visualize course concepts and a proposal for the revision and redesign of the course is presented.

Course description and structure

Applied Microbiology (LBIK10180U) is a 7.5 ECTS elective course run in Block 2 for students pursuing a master's degree in either *Biology-Biotechnology*, *Biology*, *Biochemistry* or *Environmental Science*. The course content divides into six themes or modules: (1) beneficial microorganisms from extreme environments, (2) genotyping of microorganisms, (3) detection of specific bacteria, (4) bacterial population dynamics and gene expression, (5) bacterial metabolite production and (6) microbial genomics (*i.e.* bioinformatics component). The course has no strict prerequisites for the students but recommends that students have an academic qualification equivalent to a BSc degree and have passed a basic course in microbiology.

Intended learning outcomes (ILOs)

The intended learning outcomes (ILOs) of the course are divided into knowledge, skills and competences (https://kurser.ku.dk/course/lbik10180u). The ILOs could be more detailed and define a learning outcome for each of the six themes covered in the course. For the microbial genomics theme, proficiency with bioinformatics tools and software could be listed among the skills to acquire.

Teaching and learning activities (TLAs)

Applied Microbiology is a hands-on practical course running across 10 weeks, with 20 h dedicated to lectures, 20 h to study groups, 40 h to practical exercises and 60 h to project work. The TLAs involve a weekly lecture followed by a laboratory introductory lecture and lab-exercises. For the microbial genomics theme, students receive an introductory lecture and are provided with supplementary online information in the format of tutorial slides, before commencing 4 weeks of computer-based exercises with instructors available for group discussions and guidance.

Assessment

Students must complete a weekly report following completion of each practical exercise and a final written bioinformatics project report based on the microbial genomics theme. In order to take the final oral examination of 30 minutes, 75% of the reports must be approved.

Constructive alignment and congruence

Overall, the *Applied Microbiology* course works well as seen from the student's perspective. All of the ILOs can be demonstrated through the assessment scheme of the course with the exception of the microbial genomics theme, an outlier throughout this analysis. In contrast, the other five themes align nicely and show congruence in the different dimensions. From the student perspective, the microbial genomics theme should be revised (see Appendix A). From the course perspective, the teaching-learning activities and the feedback and assessment align well (see Appendix B). Again, the microbial genomics theme is an outlier. This further supports prioritization of this part of the course. In addition, congruence in students' background is lacking. Finally, while there is congruence in course organization and management, this alignment throughout the course is broken by the microbial genomics theme. The constructive alignment model described by Biggs (Biggs & Tang, 2007) is based on the alignment of ILOs, learning activities and assessment to achieve optimal student learning. As highlighted above, the constructive alignment and congruence of this course is relatively good. However, a key issue arising from evaluations of the course is the final theme centered on bioinformatics and genomics. The course description should therefore provide more detail on the microbial genomics theme including a better description of the bioinformatics skills to acquire. Furthermore, a greater emphasis on the prior knowledge and skills needed to successfully complete the course could be provided. The requirement of students to have passed a basic course in microbiology is too vague and has resulted in students selecting the course under false pretenses. A self-test prior to taking the course could help students to verify whether they are indeed qualified to take the course (Luo, n.d.). In addition, the theme organization and management needs revision.

In this study, a design-focused evaluation (DFE) (Smith, 2008) has been used to gather information on the students' perception of the efficacy of the alignment of the *Applied Microbiology* course. While the DFE approach is very insightful, it is survey-based and focuses on the collection of evaluative data. Despite, the awareness of the microbial genomics theme being challenging, through the DFE approach the course teachers have not managed to solve the problem, which remains the focus issue from the students' perspective. To gain further insight, interviews with select students and the relevant teachers involved were conducted.

Student background and learning experience

In addition to the formal student evaluations, interviews with select students were also performed in order to gain further insight into the specific challenge of the bioinformatics module. It became apparent that students divided into two groups: *(i) students with pre-existing knowledge and skills in bioinformatics* and *(ii) students with no prior knowledge and experience of bioinformatics*. For example, students who previously took bioinformatics courses came equipped with basic skills in the subject area and pre-existing knowledge of some of the tools used in the course. This was also the case for students who had undertaken for example bachelor projects at the department, which involved a bioinformatics component. This meant they found the bioinformatics-based exercises less challenging and were happy to work independently. In contrast, students having no prior experience with bioinformatics found the computer-based exercises challenging and critically struggled to put the exercises into proper perspective and understand the information provided. Furthermore, they found working independently difficult. Overall, whether students found the bioinformatics component challenging or not, all were in agreement that the microbial genomics module is disconnected from the rest of the course.

Teachers' course perspective

Following lengthy discussions with the course teachers, it was concluded that the main obstacle within the microbial genomics theme was the large amount of information provided to students, which proved too much for them to process. A solution is therefore to keep extraneous information to a minimum and to start by setting the students few straightforward goals at the beginning of the course. In this way, the knowledge is being built stepwise and the objectives can then be linked to more complex concepts in the final project (Theme 6) (see Appendix C). Another issue identified, relating to the course overall, and a potential limitation of research-based teaching, is the shift in section personnel. The subject of the lectures and lab exercises relate to the teacher's own research and therefore when postdocs or PhD students (who typically teach the practical exercises) or lecturers leave, the ability for other teachers to take over the exercises is challenging. This also contributes to a lack of continuity in teaching and connectivity across the exercises. This can make putting the overall course content into context difficult for students. Another issue identified was the amount of theoretical information relating to next-generation sequencing (NGS) technologies and the fact that the students do not in the lab exercises gain hands-on experience with the technologies (students receive raw data output). As we now have NGS technologies in-house at the section, the course could be revised to enable the students to use the techniques, thus putting the bioinformatics teaching into a "real-world" context allowing students gain knowledge and experience with as many methods as possible taught in the lectures.

Revision and redesign of the *Applied Microbiology* course: a proposal

The *Applied Microbiology* course is run by the *Section of Microbial Ecology and Biotechnology* at the *Department of Plant and Environmental Sciences*, and is primarily based on research conducted at the section. Due to a recent generational shift in personnel combined with the rapid advance of microbial techniques and NGS technologies, the decision to revise the bioinformatics component and ultimately redesign the course has been made. Moreover, the fact that nowadays many microbiologists formulate scientific questions and analyze research data in the context of genomic information must be at the forefront of the course design. In redesigning the course, the two major concerns are *(i) how to successfully integrate bioinformatics into a laboratory course* and *(ii) how to teach a rapidly evolving field of study to a diverse group of students*. Using the principle of constructive alignment developed by Biggs and Tang, 2007, a framework for redesigning of the *Applied Microbiology* course is proposed (see Appendix D). In order to achieve this, I propose developing a research-based program where *Applied Microbiology* is an integrated course taught by researchers at the forefront of microbiology, bioinformatics and genomics. It is important to stress that the University of Copenhagen already offers courses and curricula designed to teach fundamental bioinformatics. In contrast, the aim of the *Applied Microbiology* course is to utilize bioinformatics as a teaching tool. The term "bioinformatics" can be interpreted in several ways and thus the definition most relevant to the *Applied Microbiology* course is that described by Cummings and Temple, 2010 where bioinformatics is *"research, development or application of computational tools and approaches for expanding the use of biological data"*.

A first step in the redesign process will be to revise the microbial genomics theme. Thus, in order to successfully incorporate bioinformatics into the course, I suggest building upon the bioinformatics teaching rules described by Form and Lewitter, 2011 which include keeping the activities simple by setting fewer well-defined goals and keeping information to a minimum, using activities linked to pre-existing knowledge (*i.e.* lectures, practical exercises), develop activities that build on each other enabling students to focus on learning one skill at a time, use activities to build skills and provide information through problem-based learning, and address multiple learning styles. For a comparison of the current and proposed revision of the course structure to better integrate the bioinformatics component see Appendix C.

Student ownership and empowerment are additional factors to consider in the revision process. For example, it could be beneficial to provide opportunities for student individualization to foster a sense of project ownership. Currently, for the final project report, students are divided into working groups of two where 50% of groups work on the genome assembly and analysis of one bacterium and 50% on another bacterium. Providing each student group with a unique project (*e.g.* sequencing one bacterial genome each) could maximize the opportunity for students to take ownership of their projects. Furthermore, it would give the students the chance to contribute to research while strengthening their connection to the research community. The current microbial genomics theme is designed to allow students to discover information the course teachers want the students to learn (*i.e.* conducting a bioinformatics project independently at their own pace). The strategy behind this set-up was to empower students in a bid to benefit the learning process. However, this approach proved challenging for many students and therefore an element of scaffolding must be included to aid students in accomplishing new tasks and concepts.

The course assessment should be revised to include an oral presentation to accompany submission of the final bioinformatics-based written project report. This would provide students with the opportunity to present their results to the class and to receive feedback from both teachers and peers prior to the exam. In addition, small weekly assignments to accompany the lab exercises should be included to build up knowledge and skills in bioinformatics (see Appendix C). This would allow for continuous assessment to be performed throughout the course and could further be supplemented with online multiple choice quizzes to track student learning and provide formative feedback to students.

Another factor underlying good teaching is the implementation of variation, for example the teaching environment, where it can be of benefit to use different teaching facilities (Horst & Ingerslev, 2015). This is already achieved in the current course set-up with the blend of lectures, lab-based classes, and small classrooms, which are located in close proximity to the section and thus the research environment, meaning that students can interact with the course instructors throughout the teaching day. One key difference of the microbial genomics theme when compared to the other course themes, is the physical set-up of the module (*i.e.* not lab-based). In the future, it will be important to emphasize to students the role and importance of bioinformatics in microbiological research methods. This could be supported by the introduction of an additional exercise in the form of a journal club after each lecture. The students could be tasked with reading a scientific article and then evaluate how bioinformatics methods were used by the authors to test a specific hypothesis. This would help the students to put the bioinformatics component into proper perspective and to upon completion of the course be able to propose and discuss bioinformatics approaches or tools combined with wet-lab techniques that can be used to define a hypothesis to test a given scientific question.

Redesigning the course could focus on enabling students to complete an entire study closely mimicking what is required to publish scientific studies. The course should therefore place emphasis on the current microbiological, molecular and bioinformatics techniques required to complete such studies with the aim of equipping students with both laboratory and bioinformatics skills. To assist in the development and redesign of the course, a concept map has been built as a tool to communicate the major themes of the course and how they are related (see Appendix E). Concept maps can facilitate course planning by *(i) allowing for the identification of potentially trivial areas of the course*, *(ii) identifying key themes to emphasize*, and *(iii) allow for the selection of appropriate instructional materials* (Martin, 1994). In addition, the concept map (once finalized) can be used to communicate with students and enable them to see the relationships between the core concepts and content of the course in addition to initiating student discussions to summarize course concepts. Kinchin et al., 2005 have previously shown this to be an effective way of enabling students to link and incorporate new information into their previous knowledge and thereby support deep learning.

Discussion

In order to achieve aligned teaching, there must be a maximum consistency throughout the system Hounsell and Housell, 2007. The current *Applied Microbiology* course uses appropriate teaching methods (*e.g.* lectures and practical exercises) that overall enable the ILOs to be met. However, the course has some constructive alignment challenges that relate specifically to the microbial genomics theme. Due to a change in teaching staff combined with the dynamic and rapidly changing nature of microbial methods and sequencing technologies used in microbiological research, this aspect of the course will be revised with a long-term plan to redesign the entire course. However, the first step will be to better integrate the bioinformatics component into the current course set-up. This can be achieved in the first instance by focusing on the course TLAs and assessment. As discussed, this can be achieved by using a step-wise approach to build bioinformatics skills and knowledge through the completion of small assignments each week that accompany the lab exercises, and continuous assessment to track the learning and accomplishment of bioinformatics tasks by students. Additional assessment in the form of online multiple choice quizzes and an oral presentation to accompany the bioinformatics based report would provide additional feedback to students.

The need for wet-lab microbiologists to have bioinformatics skills is increasing and must become an essential part of their education (Luo, n.d.). However, despite this, teaching of wet-lab skills and bioinformatics is often performed independently. If properly integrated into *Applied Microbiology*, or other biology-based courses for that matter, bioinformatics has the potential to promote student learning. This is based on one of the principles of promoting learning that *"learning* is *promoted when learners are engaged in solving real-world problems*" (Cummings & Temple, 2010). In the *Applied Microbiology* course, there are many opportunities to incorporate real-world examples and new knowledge into learning and bioinformatics-requiring laboratory exercises for example, *whole genome sequencing and analysis of bacteria isolated from a suppressive soil found to produce anti-fungal compounds following co-culture screening*. By using a combination of lab-based exercises (*e.g.* strain isolation and screening, whole genome sequencing) combined with bioinformatics activities (*e.g.* genome assembly and mining), there is a direct link between learning through the course work.

There are however, several challenges associated with the incorporation of bioinformatics and computer-based activities into student learning such as infrastructure and logistics, teacher knowledge and experience of bioinformatics, diversity of students and teaching objectives Cummings and Temple, 2010. In the case of *Applied Microbiolog*y, as the course does not teach fundamental bioinformatics, the issue of infrastructure and logistics does not present itself. The course utilizes the increasing availability of online resources and access to the CLC software (Qiagen Bioinformatics) for genomics analysis with an easy-to-use interface that does not require knowledge or use of programming languages, and can operate on standard computers and laptops. The application of user-friendly interfaces is particularly important as the course caters to students with diverse backgrounds who come with varying degrees of bioinformatics experience and comfort working with computer-based exercises. Interestingly, in the age of internet and online resources, the average experience of students with web browsers and different interfaces should be advantageous to the incorporation of computers and technology into education however for many students on *Applied Microbiology* this seemed challenging. Teacher knowledge is another potential issue in particular if teachers are not actively using bioinformatics in their research. This can lead to challenges in developing lecture material and learning activities. Thus, the continued education and training of teachers involved in the course will be paramount.

The current and future course design has previously and will continue to use a research-based teaching approach. This approach involves presenting research findings and thus uses relevant examples allowing teachers' to put the course content into proper perspective. A positive outcome of such research-based teaching is that the teaching can also contribute to research as previously demonstrated by Feldon et al., 2010. For example, students can identify potential flaws in studies or raise questions and contribute comments that may lead to new research (Bonderup & Dolin, 2015). Research-based teaching has therefore the potential to generate new and valuable research questions and data. In the proposed redesign of *Applied Microbiology*, research-based teaching will continue to play a prominent role in the course. Based on experience from the current course design, and in accordance with the research-teaching nexus at Oxford, taking a research-based approach has proved successful in motivating both students and teachers, providing better resources for students including access to research networks and importantly has allowed students to feel part of a research community (Bonderup & Dolin, 2015). However, limitations of this teaching approach include the complexity of research and the way in which such research knowledge is constructed. In addition, there is not a common course syllabus as each instructor is teaching their field of expertise and to a degree interest. One solution in this course is use a common organism for example *Pseudomonas* bacteria, which are good research and teaching tools due to their diverse possibilities for both lab and bioinformatics studies. Another important consideration of research-based teaching is to take into consideration cost issues and timing of experiments.

Based on the constructive alignment and congruence analysis of the current *Applied Microbiology* course, student background is also an important issue to factor in. Going forward it could be useful to perform a qualitative analysis of student learning by using Vygotsky's Zone of Proximal Development to investigate student knowledge and learning potential (Vygotsky, 1978). The current course design already combines the zone of proximal development with the lectures using peer instruction and small group discussions in the practical exercises to compensate for differences in student background. Furthermore, it appears (for some students) necessary to introduce the scaffolding concept described by (Wood et al., 1976) to support the students through the zone of proximal development. This is particularly relevant as the course is research-based and therefore uses a more problem-based teaching approach to achieve deep learning. Finally, while broader incorporation of bioinformatics into the course is necessary, careful integration of this component is required to safeguard that the course remains at its core laboratory-based, and does not transition into a fully computer-based course.

Once revised, further improvement of the constructive alignment and congruence in the course could be explored through the adoption of a student assisted course design approach (Birgbauer, 2016). This approach would benefit both the students and teachers. Students would gain insight into the teacher perspective of the course and understand the time and effort involved in developing a course. In addition, students would gain skills in designing a new curriculum and feel part of a community involved in designing a better course for future students. Teachers would benefit from direct feedback from students on aspects of the course that work and do not work. Having students involved in the redesign of the course could also help to promote the course to fellow students. Furthermore, the successful implementation of bioinformatics teaching and computer-based learning will require the continuous tracking of student learning and the collection of assessment data on the proficiency of student learning outcomes.

Conclusion and Future Perspectives

The *Applied Microbiology* has some constructive alignment issues most notably the microbial genomics theme. While the course is consistently positively evaluated by students, the decision to revise and ultimately redesign the course is an opportunity to develop new hands-on educational approaches for the combined teaching of wet-lab and bioinformatics skills in microbiology. The ultimate goal is to offer students a coherent, connected and integrated learning experience.

Redesigning any course is challenging. Furthermore, for a course such as *Applied Microbiology* which has been running since 2008, it is important to note that the pace at which new technologies are developed means that many of the techniques currently taught on the course will become obsolete in a matter of years. Consequently, it will be necessary to continually develop and revise the course content to ensure that the material covered is relevant. This is critical to ensure the development and education of highly-qualified students. This applies equally to course teachers who will need to make sure they continually develop their own skills in the field to effectively translate knowledge of new technologies and research findings into teaching. In the future, it will become necessary to incorporate bioinformatics into the teaching of not only microbiology but all branches of biological sciences. This will be critical to meet the growing demand for researchers with both wet-lab and bioinformatics skills.

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A Analysis of the *Applied Microbiology* student perspective

The student perspective

Course evaluations enable teachers to determine whether the course delivery and structure requires revision. Importantly, course evaluations provide feedback in the form of written comments from students. This enables us to "see the course through student eyes". Student perceptions of the course were determined using a questionnaire similar to the *Experiences of Teaching and Learning Questionnaire* (ETLQ) previously described by Hounsell and Housell, 2007. The students' perceptions of different aspects of their environments (*e.g.* Learning, Clarity, Feedback) were examined (Table 12.1). For each item, the students responded on a scale of 1-5 where 1 indicates a strong disagreement with the item and 5 indicates a strong agreement with the item.

Table 12.1. Students' perceptions of their teaching-learning environments (ETLQ scales) adapted from Entwistle et al. (2003).

Learning	Achievement of ILOs
Clarity	Clear aims and curricular congruence
Material	Relevant teaching material for course
Feedback	Clear and supportive guidance and feedback on set work (written reports)
Information	Access to necessary course information
Reward	Course has been rewarding experience
Assessment	Assessing understanding and critical thinking (oral exam)

The following analysis is based on data collected from the last three consecutive years of teaching on *Applied Microbiology* completed by a total of 53 students (Figure 12.1). The data shows that the majority of items are positively perceived by the students.

Additional information in the form of written feedback from students was also obtained. When analyzing the aspects of the course that the students perceived as working well, positive words such as "good", "connection", "great", "interesting" appear frequently. When analyzing the comments in more detail, it becomes apparent that overall, the students' perceptions of the course are positive with students seeing the course as well structured with a constructive alignment between the teaching-learning activities:

S1: *course was very nice organized and the lab exercises and the lectures were nicely connected.*

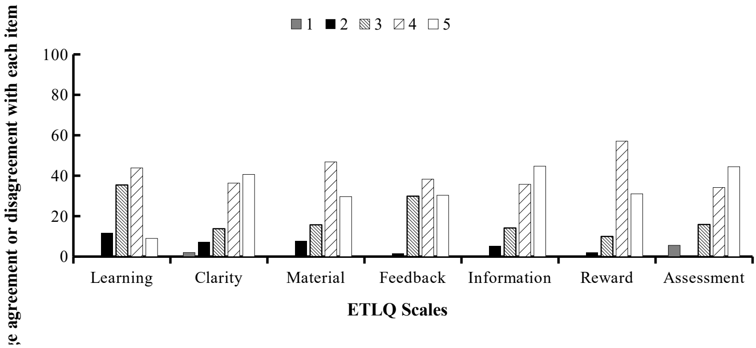


Fig. 12.1. Students' perception of *Applied Microbiology*. Percentage agreement or disagreement of students to each item (Learning, Clarity, Material, Feedback, Information, Reward, Assessment) on a scale of 1-5 representing total disagreement (1) to total agreement (5). Data represents the mean of three independent questionnaires and bars indicate standard error of the mean (SEM).

S2: *it was very nice to have both lab work and lectures. The connection between those were very clear.*
S3: *the course does a good job applying real-world examples of what we can expect to do in the real world.*
S4: *Nice with so much hand on experience with different methods combined with theoretical relevant lectures.*
S5: *I think overall the course worked very well, good alignment between the weekly themes, teaching and exercises.*
S6: *alignment between lectures and practicals.*
S7: *how the course combined the different topics and methods was great.*

This is in contrast to the negative aspects of the course for which the words "confusing" and "bioinformatics" are overrepresented. The students highlight a lack of congruence between the final course theme on microbial genomics (also referred to as bioinformatics) and the rest of the course:
S8: *the main project could have been organized before the new year and not so close to the examination dates.*
S9: *genomic report intro started before Christmas break*
S10: *a brief overall background lecture to the theory behind the gene annotation project*

S11: *there is way to many guiding papers for the genome project. It is confusing to find my way around what I should include and in what way. It would have been nice if there was only one file containing all the information you need in a order logically.*

S12: *the bioinformatics was not very exciting and very difficult. It seemed we just had to try all sorts of different websites.*

It is important to note, that the structure of the microbial genomics theme is slightly different from the other themes covered in the course. An introductory lecture to the theme is provided followed by a presentation of the project group work. The subsequent learning activities involve understanding and gaining experience working with different bioinformatics tools and software to assemble and analyze a bacterial genome. There are no laboratory exercises – all activities are computer based. In addition to the introductory lecture, mini-tutorials aimed at clarifying different analysis stages of the project are given.

B Analysis of the *Applied Microbiology* course perspective

The course perspective

The aspects of the course that seem to be aligned are the teaching-learning activities, and the feedback and assessment. The course is structured using teaching methods (*e.g.* lectures and practical exercises) that enable the ILOs to be met. The course is heavily method focussed and thus the lectures provide the theory behind different techniques used in microbiology, and provide examples of how such tools can be implemented to solve real-world problems within microbiology. The lectures are followed by laboratory-based exercises giving students the chance to conduct practical experimentation in microbiology. The questionnaire data indicated congruence of teaching-learning activities as evidenced by the students' comments S1-S7.

The feedback and assessment also appears to be relatively well aligned with no student comments aimed specifically at this dimension indicating congruence of feedback and assessment. Two types of feedback and assessment are provided: written reports and an oral exam. The reports are used for the students to gain feedback on their understanding of the six themes prior to the oral exam. This continuous assessment appears to work well. The oral exam is used to test whether students have successfully learned

what the course ILOs state the students should have learnt. The format of the oral exam involves the presentation of a case study relating to a theme covered during the course. Following presentation of the case study, students are questioned on all aspects of the course including the microbial genomics theme. However, during the oral exams it was observed that the majority of students appeared to struggle with questions relating to the microbial genomics theme. This issue was also made apparent from the student course evaluation:
"The bioinformatics part would have been nice if there had been a better explanation to it or just a bit more time because I think a lot of us find it difficult to discuss about this topic for the exam"

This was surprising considering prior to the exams the students submitted a project report based on teaching-learning activities from the microbial genomics theme and for the most part, the content indicated understanding of the subject. This shows that there is a lack of congruence in feedback and assessment relating specifically to the microbial genomics theme.

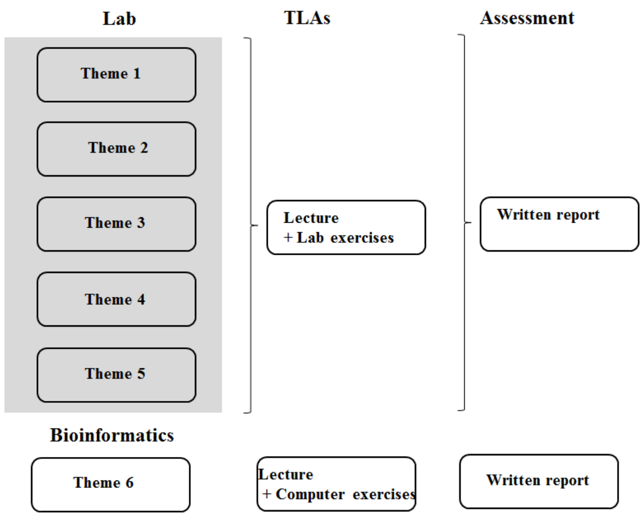
Another aspect of the course needing improvement is congruence of course organization and management again specifically aimed at the microbial genomics theme. As described above, students found this theme in contrast to the rest of the course, poorly structured and confusing. Every year on this course, the students' knowledge and skills vary widely. Taking this into consideration, the decision was made to give small tutorials on different parts of the analysis which are then uploaded to Absalon and available to students to work through in their own time. While the aim of this approach was to help the students it turns out it made them more confused. This leads to another important aspect of the course requiring improvement - congruence with the students' backgrounds. This was also a key point made by the students:
S13: *A brief overall background lecture to the theory behind the gene annotation project. There are many different levels on knowledge regarding genetics among the students*
S14: *Overall very low educational level. As a biotech student from KU I feel like this course could have easily been part of my* 2^{nd} *year on the bachelor. I know you have to take into account that people come from different backgrounds but I have not learned much new.*
S15: *My only suggestion is to highlight the importance of background knowledge for the students taking this course that are not studying biology or biotechnology. I believe this should be highlighted in the course description*

in order for someone to make a better decision about whether he should consider taking this course or not.
S16: *the bioinformatics part is an excellent idea, BUT there has to be much more background. I am the only person in my group who have had a bioinformatics course, and I've felt like a teacher during the project work because no one has a clue what they are doing.*

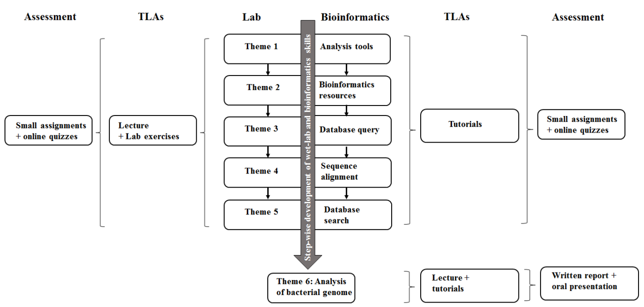
This aspect could by improved by clarifying in more detail the qualification requirements of students which currently is stated in the course description as *"students are expected to have passed a basic course in microbiology"*. For example, the course description should emphasize that the course involves microbiology teaching at an advanced level building upon fundamental knowledge within microbiology, molecular biology and molecular genetics. In addition, it could be worth mentioning that while prior knowledge of bioinformatics is not a requirement it would be an advantage. While the course teachers are cognizant of the diversity in student backgrounds, they are also aware that the needs of all students, particularly those lacking a solid background in microbiology cannot be met appropriately due to time and resource constraints.

C *Applied microbiology* course: current versus proposed structure

(a) *Current course structure*

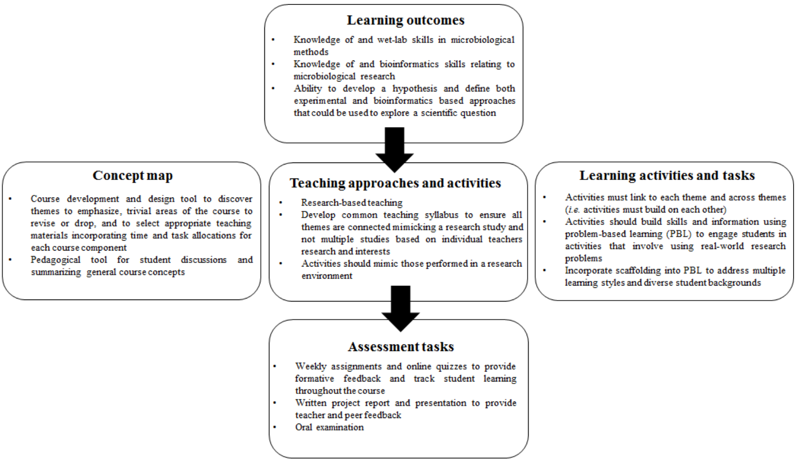


(b) *Proposed course structure*



Each theme covers the theory and application behind one or more techniques/technologies that are used in microbiological research. Upon completion of the final report, students should be able to define experimental and bioinformatics approaches to explore a scientific question within the field of applied microbiology.

D Proposed framework for redesigning *Applied Microbiology* based on the constructive alignment principle.



E Concept map for redesigning *Applied Microbiology*