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Student motivation and activation by research-based laboratory exercises

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Introduction

Laboratory exercises are an integral part of the undergraduate bioscience curriculum and typically represent the "hands-on" component of lecture-based courses. It is widely believed that the laboratory provides the learning forum where theory and practice merge and where students acquire practical techniques and skills for future employments in the bioscience-related field. However, recent studies revealed that there is in fact a large discrepancy, both among and between students and teachers, in the perception of the exact function of the laboratory component and its correlation to the lecture part of the course content (Russel and Weaver; 2008, and references therein). Traditional laboratory design is often based on written manual instructions where the students' explicit goal is to follow exactly the procedures and to complete the experiment. Thus, success in the laboratory is, from this perspective, solely based on getting the pre-determined answer from the experiments, and not to learn the theory behind the practice of the laboratory settings. This contrasts greatly with the expressed purpose for the laboratory from the science education point of view, which includes, in addition to the practical skills, an understanding of scientific concepts, interest and motivation, and problem solving capabilities (Hofstein and Lunetta; 2004; Hofstein and Mamlok-Naaman; 2007; Russel and Weaver; 2008). Efforts to accomplish these goals include laboratory teaching approaches that are "inquiry-based". This broad term commonly refers to the engagement of students in research-driven activities which can be implemented at various levels (Rehorek; 2004; Howard and Miskovski; 2005;

Cunningham et al.; 2006; Weaver et al.; 2008). Consistently, Weaver et al. (2008) proposed that inquiry-based approaches occur on a continuum, ranging from some being very guided by the instructor to others being very open-ended with high student autonomy and responsibility (Figure 7.1).

Fig. 7.1. Model illustrating that incorporation of inquiry and research in laboratory classes exists on a continuum with different degree of student responsibility. Reproduced from (Weaver et al.; 2008).

A major aspect of the inquiry-based approaches is to create an environment where the students participate in the generation of new knowledge and contribute to a larger research effort. Thereby, the students' focus is directed away from the pre-determined outcomes of the traditional laboratory exercises towards the scientific processes of discovery. These include the formulation of scientific questions, making observations, collecting and analyzing data, revisiting experimental settings due to failure, and communication of the results. Several studies have confirmed that students benefit from these research activities and that integrating authentic research in teaching is a way to improve students' learning and motivation (Jenkins et al.; 2003; Howard and Miskovski; 2005; Russel and Weaver; 2008).

Revision of traditional laboratory classes towards inquiry- and research-driven activities follow experiences from successful efforts to incorporate active learning pedagogies in traditional lecture-based courses. Research provided strong evidence that students learn more if they "*read, write, discuss, or be engaged in solving problems... than just listen*" (Bonwell and Eison; 1991). Based on these findings, several teaching/learning activities (TLAs) were developed that range from group discussion, interactive and peer-teaching, to collaborative and problem-based learning (Biggs and Tang; 2007). Common to all these approaches is the attempt to create a learning atmosphere that increases students' interest and engagement in the

activity or problem-solving task itself and hence, to enhance their "intrinsic" motivation as driving force for deep learning (Biggs and Tang; 2007).

Problem definition and objectives

The course "Plant Molecular Biology" is part of the bachelor program at the University of Copenhagen and open to students of various disciplines including Biology, Biochemistry and Biomedicine. The course is given in block structure over a period of two months and consists of 3 h of lecture and a full day of laboratory each week. Lectures cover textbook knowledge as well as student seminars related to various topics in plant growth and development, hormone signalling, genome organisation and gene regulation, environmental stress and plant disease. The laboratory deals with the theoretical background and application of basic methods and techniques in molecular biology and genetics and is divided into different labs that continue over several weeks. Thus, students need to handle several rather independent assignments with different instructors at the same day. Being an instructor on different course sections over the last years, I often had the impression that students methodically followed the protocols but had difficulties to grasp the theoretical backgrounds and adapt to the various independent experiments during a course day. This structure resulted frequently in high level confusion during the practical part and a lack of active participation during the theoretical introductions to the different labs. Therefore, I sought to overhaul the laboratory, being aware that changes on the part under my responsibility had to be applied "isolated" within the context of the other labs and lecture classes which were kept unchanged compared to previous years. In revising the lab, my objectives were as follows:

- Increase students' motivation and engagement in the lab
- Expose students to a real-life lab situation and scientific processes of discovery
- Let students participate in a larger research effort
- Help students to see the "big picture" and make connections between concepts
- Enhance students' ability to communicate their results
- Relate the lecture to research-driven contents of the lab

Methods

Research-driven problem and lab manual

The laboratory part "Cloning" is distributed over 7 course days once a week and based on a lab manual entitled "construction of epitope-tagged proteins for interaction". The lab has been running since 2003 with a constant number of students (12-14, typically organized in teams of two students) in a nearly unchanged manner under the responsibility of different instructors. I was the main instructor in the past two years (2007-2008) and used the inherited lab manual with only a few formal changes. I already felt in these years, that the manual was outdated because the exemplary constructs that were cloned for interaction studies had been used some years before in the lab without any success. Thus, student classes were repeating over several years cloning work that was known to be of no further relevance, only as cloning example *per se*. Therefore, the major task was to change the artificial and outdated lab manual towards an authentic research effort that is part of an ongoing research project in the lab. In addition, changes were made under the pragmatic consideration that the manual could be easily adjusted in the next years according to the future project status. However, since the overall structure and subjects of the course did not change, the research task within the cloning lab had to be closely aligned with the previously defined intended learning objectives (ILOs) of the course (see Appendix A).

The research task of the modified "cloning lab 2009" arose from one of the major projects in our lab dealing with the "regulation and execution of cell death in plant innate immunity". We have recently shown that programmed cell death (PCD) associated with a pathogen-triggered defence reaction (hypersensitive response, HR), engages an ancient vesicular pathway for degradation of cellular contents, termed autophagy (greek for "self-eating") (Hofius et al.; 2009). Efforts to identify regulators of this PCD reaction suggested that two proteins, ACCELERATED CELL DEATH 11 (ACD11) and its closest homolog (ACDH1), could be directly or indirectly linked to autophagy via protein interactions with essential autophagy effector proteins (ATGs). To verify this hypothesis, protein-protein interactions need to be demonstrated *in vivo*, which is commonly addressed by co-immunoprecipitation of the candidate proteins. Thus, the modified lab dealt with cloning of epitope-tagged proteins for *in planta* verification of ACD11-related protein complexes. To emphasize that the task would help to solve a genuine research problem, the 12 students were not only divided

into lab teams of two students but also in two major groups (teams #1-3 and #4-6) that would contribute to the overall research project by cloning in a complementary manner two constructs (ACDH1 and ATGx) with different epitopes for the co-immunoprecipitation assay. The integration of these research-driven aspects into the lab was accommodated by providing a thorough introduction into the background of our research project in the lab manual. Furthermore, it was important to make the students aware that cloning of these constructs has not been done before. Thus, it was highlighted in the manual that the protocol should only be regarded as guideline and adjustments are likely to occur according to the progress and/or problems during the course.

Teaching/learning activities

An essential component of the attempt to create a motivating and authentic research environment was the integration of different teaching/learning activities (TLAs) into the introductory lectures to each lab day. Based on experiences from previous years, special emphasis was placed on incorporating questions, both convergent and divergent (Biggs and Tang; 2007), as well as group work to increase students' participation during the lecture. With respect to the introduction of the research-based aspects of the laboratory, the prelab lecture of the first day was of great importance and was meant to present to the students the "bigger picture" and conceptual context that the research task is part of. Most TLAs during the relatively short (15-30 min) introductions to the following lab days concentrated on recapitulating the previous lab day(s) including the status of the cloning, technical problems and respective solutions that were discussed and developed in the class. Short group assignments (2-4 people) were combined with individual questions and the whiteboard was typically used to collect the answers (either by students or instructor) prior to the class discussion. Both powerpoint slides and the whiteboard were used to outline the ILOs of each lab day, to illustrate the theory behind the different methods (e.g. PCR, restriction, ligation, transformation, plasmid purification), to show the different results of the various cloning steps (e.g. DNA gel pictures), and to indicate the overall procedures (with emphasis on the modifications compared to the lab manual) for each lab day.

Lab report assignment

One important approach to increase the student ownership and engagement in the research-driven lab exercise was the team assignment to present their results in a "real-life" lab report. The rationale behind this written format was communicated as follows; (1) that research with gene-modified organisms generally requires proper documentation, (2) that cloning details and sequences of each construct need to be documented to allow further use in the research project, and (3) that there is a specific scientific way how research is transmitted to the community, which usually requires practical training. Therefore, students were asked to write the lab report in the form of a scientific paper, including Summary, Introduction, Materials and Methods, Results and Discussion. During most of the lab days, the recapitulation of the methods and results from the previous week(s) were presented in relation to the assignment, which was typically highlighted by one ILO at the respective course day. Furthermore, the final analysis and sum-up of the course was closely aligned with the lab report task. Lab reports were asked to be completed one week after the last course day and the teams received general comments at the Q & A session in preparation of the exam as well as individual corrections and comments in electronic form. However, it is important to note that lab reports as such were not part of the final exam.

Constructive alignment of lecture and lab content

Since I had the opportunity to give the disease lecture of the PMB course as part of my teaching evaluation, the content of the inherited lecture was modified to constructively align the ILOs of the lecture and laboratory part. Hence, the disease lecture aimed to broaden the introduction into the multilayered nature of the plant innate immune system and to elaborate on specific issues related to the research-driven lab content. This included the concepts of programmed cell death, autophagy and multi-protein complexes in pathogen-triggered defence responses.

Course evaluation

In order to evaluate the acceptance and usefulness of the research-driven aspects of the lab content as well as the lab report assignment and different

TLAs, a questionnaire with 14 questions were handed out to the students at the end of the course (Appendix C). Questions 1-13 were designed in multiple choice style with 5 categories ("excellent, very good, reasonable, bad, terrible" or "very much, much, reasonable, not much, very little") and followed by an empty field for comments and suggestions for improvements. To simplify the interpretation and presentation of the results, answers in categories 1 and 2 ("excellent, very good" or "very much, much"), as well as 4 and 5 ("bad, terrible" or "not much, very little") were fused and designated as "positive" and "negative", respectively. Category 3 ("reasonable") was assumed to be "indecisive/neutral" towards the issue addressed in the questions. In general, the number of questions was kept to a minimum since the questionnaire was a supplement to the overall course evaluation form handed out by the course leader every year.

Results and Discussion

Revision of "cloning lab" towards research-driven activities

Since the overall structure and content of the different lecture classes and labs were not subjected to any major changes, the "real-life" research task implemented into the "cloning lab" was fitted into the context of the intended learning outcomes (ILO3, ILO8, ILO10 and ILO11) of the PMB course (Appendix A). Accordingly, the objectives of the cloning lab were outlined in the modified manual and/or the introductory lecture as follows:

- *To define the principles behind PCR, cloning and sequencing*
- *To evaluate the use of different epitope tags for protein complex analysis*
- *To use databases and bioinformatics tools to select candidates for protein interactions*
- *Acquire knowledge on the role of protein complexes and networks in plant immunity*
- *To design strategies for protein complex analysis using co-immunoprecipitation*

Based on these ILOs, students were involved in an ongoing research effort dealing with the analysis of protein networks in the regulation of plant immunity and cell death pathways. More specifically, the students were asked to "help" with the cloning of two epitope-tagged constructs to facilitate the *in planta* analysis of the potential interaction between two

candidate proteins, ACDH1 and ATGx, by co-immunoprecipitation. In order to increase the value of the students' contribution to the project, the 6 student teams were divided into two major groups, so that both constructs could be cloned in parallel during the lab. The lab manual provided all necessary protocols for the different cloning steps (PCR amplification, DNA digestion and purification, ligations and transformation in *E. coli*, colony-PCR, plasmid isolation, sequencing reactions) as well as the gene-specific details (DNA sequence, restrictions sites, plant expression vectors) for both constructs. To give the students more ownership of their cloning tasks, the relevance and importance of the laboratory for the overall project and thus, for the generation of new knowledge, was illustrated as flowchart in the lab manual introduction (Appendix B). It was important to emphasize to the students that the lab manual was meant to serve as "handbook" and "guideline" for the different methods rather than being an "authority" that they should follow without further thinking (Russel and Weaver; 2008). Accordingly, various adjustments were made to the protocols during the progression of cloning, which corresponds to a real-life lab situation. In summary, the revision on the laboratory content could be described as research-driven "guided-inquiry" (Figure 7.1) where the "*instructor still plays a pivotal role in providing both the questions to be asked and the means to obtain and evaluate the answers*" (Howard and Miskovski; 2005). Nevertheless, students' perception of the quality and usefulness of the cloning lab manual appeared to be heterogeneous, since a relatively high proportion (45%) of the students were indecisive compared to the students that had a positive impression (55%) (Appendix C, Q3). This could indicate that some students kept indeed a traditional attitude toward the "authority" of the lab manual so that modifications during the lab would simply appear as mistakes in the manual and not as "real life" adjustments.

Cloning results and lab reports

Overall, the cloning efforts of 6 teams (12 students) resulted in successful generation of one construct (pCAMBIA1300-Myc:ATGx), which contained the inserted gene with the correct sequence and orientation (non-directional cloning using a single restriction site can cause two alternative ways of insertion into the vector plasmid). The two other teams from this group were able to identify potentially positive, plasmid containing *E.coli* colonies by colony-PCR. However, subsequent sequencing of the

isolated plasmids revealed only empty vector plasmids, which could be due to incorrect labelling during colony-PCR and/or plasmid isolation. One team involved in the cloning of the second construct (pCAMBIA3300-HA:ACDH1) generated a plasmid with the correct insertion but wrong orientation, whereas the two other teams were only able to identify empty plasmids. Therefore, the cloning approach was only partially successful in terms of progress in our research project. However, the variability in the results and success rates of the different teams provided the "perfect" platform to teach "troubleshooting" skills and to incorporate scientific reasoning, critical thinking and collaborative problem solving into class discussions, in particular at the summing up part of the final lab day. In addition, the students were forced to wrestle with imperfect data during the preparation of the lab reports. This assignment generally aimed at enhancing the students' ability to communicate scientific results, which was indicated by expanding the before mentioned ILOs in the introductory lecture as follows:

- To acquire knowledge on writing research reports and documentation of laboratory work

In agreement with this objective, parts of the introductory and recapitulating lectures to the various lab days were dedicated to the way of presenting the scientific background, protocols and results in the lab report. Five teams delivered the lab report at the requested deadline. One team had apparently difficulties in finishing the report because one team member quitted the course a few weeks before the end and the remaining student never sent the document, although promised. The obtained reports gave the overall impression that most of the students had little experience in presenting their results in the requested scientific format of Summary, Introduction, Materials and Methods, Results and Discussion. Instead, some students showed the tendency to stick to the manual and/or uploaded power point slides and simply rephrased or copied parts of the introduction and protocols for their reports. Others reduced the Introduction and Discussion to a minimum and concentrated only on the presentation of their results in form of gel pictures. However, one group apparently put much effort into the assignment and produced a very good lab report in the requested research paper style including even an Abstract! Also, they succeeded in writing a Materials and Methods section where they got rid of the structured daily format of the manual. Interestingly, these students didn't appear to have much practical experience in the lab, but they showed a lot of interest into the subject and were finally the only ones that succeeded with

their cloning task. These obvious differences in the students' attitude towards the preparation of the lab report were also reflected by the answers to the respective questions in the questionnaire. A noticeable number of students stated that the lab report assignment improved their learning motivation only "reasonably" (27%) or "not much" (18%) (Appendix C, Q12). Consistently, 27% of the students did not learn "much" from the lab report and additional 27% felt only a "reasonable" effect on their learning outcome (Q13). Nevertheless, a slight majority of the students (55%) still had a positive feeling towards the lab report assignment for their learning motivation.

Student motivation and engagement

One of the major objectives for the revision of laboratory and lecture contents was to enhance the students' engagement and motivation during the course, which is the prerequisite for deeper learning (Biggs and Tang; 2007). An essential supplement to the research-driven activities was the incorporation of suitable TLAs to increase students' active participation during the lectures. Conceptual questions raised during the introductory lecture to the lab as well during the disease lecture were typically followed by short team (2 students) or group discussions (4 students) and subsequent presentation of the group answers by a "spokesman". This method also proved to be increasingly important during the recapitulating sessions in the beginning of each lab day, since the two best performing students (males) tended to dominate the class when convergent questions were expected to be answered by individuals. In particular, the majority of the female students (9 females vs. 3 males) seemed to be hampered from active participation, and the group discussion format significantly helped to avoid this situation. Nevertheless, a big portion of the students (72%) stated that questions during lecture and exercises were generally helpful to increase their active participation (Appendix C, Q10). Similarly, the group work during the introductory lecture of the cloning lab gave a positive impression to the vast majority of the students (82% vs. 18% "indecisive", Q2), whereas the group activities to recapitulate the contents of the previous course were only positively acknowledged by half (50%) of the students (compared to 50% "indecisive" students, Q6). This result, however, did not influence the overall perception of the general course introduction vs. the introductions to the different course days, since a positive impression was

shared by the great majority of students in both cases (77% and 73%, respectively; Q1&4). Nevertheless, the attempt to emphasize the ILOs at the beginning of each course proved to be less successful, since a higher ratio of the students (55%) was indifferent towards the quality and/or usefulness of their presentation (Q5).

In terms of students' motivation and engagement, the evaluation revealed a positive learning environment during the cloning lab (64% positive vs. 36% indecisive, Q8), which was noticeably better than the overall motivation during the other lab exercises (45% positive vs. 55% indecisive, Q9). One reason for this notion could indeed be found in the implementation of research-driven activities. ˜72% of the students stated that participation in a research-based exercise with uncertain outcome (open-end) improved their learning motivation (Q11), which was one of the major goals of this project. However, as mentioned before, the motivating effect of the lab report assignment was less pronounced. Two answers to the empty field question (Q14) could give an indication for the different perception of the lab report assignment. One student wrote that "*I have done a lot of reports, the outcome of that part was limited, but for people with no such experience it is a very good exercise*" . . . whereas the other one said that it "*would be better if we're encouraged to write and hand-in lab reports after each day."* Therefore, it appeared that the students had a very traditional attitude towards the lab report, which was simply regarded as protocol of the lab work as done in traditional verification laboratories. Thus, the lab report assignment was apparently not perceived as important part of the research-driven curriculum in order to practice and improve the scientific communication skills.

Conclusions

The results of this project gave the strong impression that incorporation of research-driven activities into "traditional" laboratory classes, even on a low level of student responsibility (Weaver et al.; 2008), can help to increase students' motivation and engagement. Students seemed to acknowledge the uncertain, "open-ended" nature of the laboratory settings and appeared to be stimulated by participating in an authentic research effort. In this respect, it was essential to take various opportunities during the introductory lab and disease lecture(s) to align the laboratory task with the overall research context and to make connections between the underlying concepts of innate immunity, cell death pathways and regulatory protein networks.

Accordingly, the assignment to write the lab report in a scientific format also aimed at forcing the students to elaborate on scientific background and hypotheses of the research project. However, the varying quality of the reports received indicated that considerably more time is needed to instruct and guide the inexperienced students towards "research-based" lab reports in an appropriate format. Students' perception of the lab report still seems to originate from the traditional laboratory design, where the answers of the "verification" labs have to be communicated to the instructor to complete the assignments. In this context, training of scientific communication and critical thinking skills are not the primary focus of the reports as it is intended in a research-driven laboratory curriculum. Therefore, future attempts to incorporate scientific lab report formats into the laboratory should aim at including the report assignment into the course assessment.

The TLAs integrated into the lectures helped pretty well to increase the interaction with the students and to create an overall atmosphere of student engagement and motivation. On this basis, the spectrum of TLAs can now be further expanded, for instance with ultra-short essays at the beginning and end of the class. The students are asked to respond to short questions regarding the lecture/lab content which should (1) help the teacher to quickly detect progress and problems of teaching and learning, and (2) force the students to do the pre-reading of the lab manual (one-/three-minute essays, Biggs and Tang (2007)). The experiences from this year confirmed my impression, that the lack of preparedness of students in the laboratory classes with changing labs and instructors is one of the main issues to be addressed in the future.

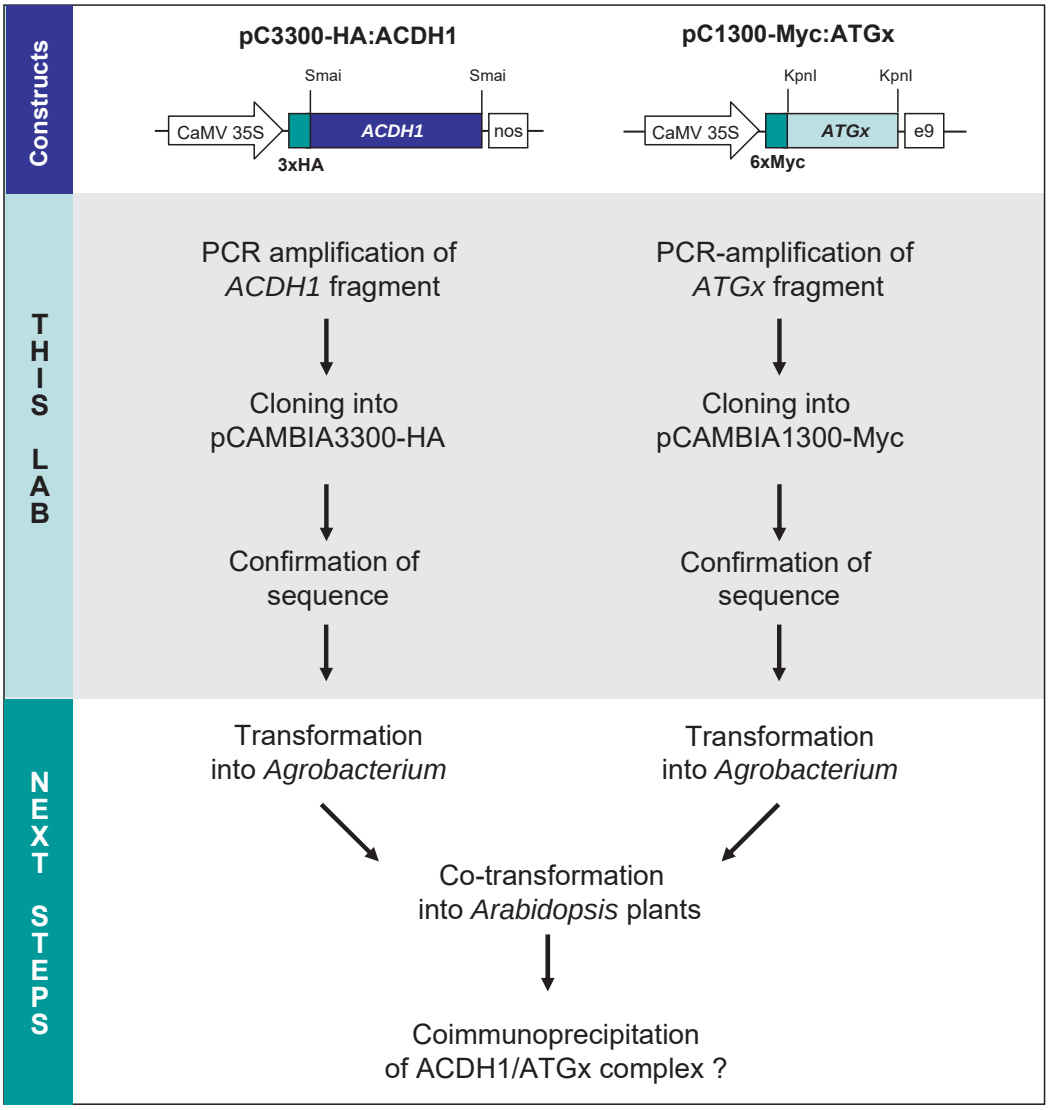
As mentioned, the research-based activities were implemented on a relatively low inquiry-level since the context of the other labs and lectures were not subjected to any major changes. Future revision on this course should be an overall effort, which provides the possibility to incorporate a spectrum of methods and activities and thus to progress towards more open-ended inquiry projects. These should be of great benefit both for students and teachers/researchers (Howard and Miskovski; 2005).

A Appendix: Intended learning outcomes (ILOs) translated from the PMB course description

1. Explain the plant Arabidopsis development and anatomy
2. Identify phenotypic mutants
3. Describe plant-pathogen interactions
4. Explain the effect of plant hormones jasmonate, salicylic acid, auxin and gibberellin
5. Perform epistatic analysis
6. Explain the forward and reverse genetic screens
7. Gain knowledge of other plant-model organisms
8. Use bioinformatics for simple purposes, such as that for annotating genes, get ideas on protein function, suggest protein complexes (Rosetta Stone) and find mutants
9. Interpret the type of examples of experimental data is introduced at the course
10. Suggest attempt to answer the scientific question
11. Define the principles behind cloning, PCR, sequencing, real-time PCR, mutagenesis, epitope tagged proteins, reporter genes, marker genes, transposable-tagging, plant transformation and selection

B Appendix: Final constructs and flow chart of the "cloning" lab

Final constructs and flow chart of the "cloning" lab as well as next steps to perform co-immunoprecipitation of the putative ACDH1/ATGx complex in plants.



C Appendix: Results of questionnaire

All contributions to this volume can be found at:

http://www.ind.ku.dk/publikationer/up_projekter/2008-1/

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