Scaffolding Undergraduate Students in Intuitive Problem Solving Strategies for Designing Experiments in Biotechnology: an Evaluation Study

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Teaching and Teacher Education

RESEARCH REPORT

Scaffolding Undergraduate Students in Intuitive Problem Solving Strategies for Designing Experiments in Biotechnology: an Evaluation Study

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One of the goals of science education is that students acquire the knowledge, skills and attitude to perform scientific research. However, current curricula in science education seem to fall short in reaching this goal. A previous explorative study aimed to learn about the characteristics and opportunities of an innovative educational approach to guide first year biology undergraduates in designing experiments in molecular biology (Postma, 2013). These findings resulted in a change in the curriculum of the first year biotechnology course of the bachelor's study of biology at Utrecht University, the Netherlands, where an assignment was created by the course's coordinator based on the findings of the previous study. In the current study it was evaluated whether this new assignment has led to students acquiring the metacognitive procedural- and conditional knowledge essential for experiment design. A small group of seven first-year biology students who were enrolled in the course participated in the evaluation. In the evaluation the students were tested on their knowledge on cognition by completing an assignment similar to that of the biotechnology course. Results showed that students acquired the necessary metacognitive procedural knowledge regarding experiment design. However, due to a lack of metacognitive conditional knowledge students were not able to apply their knowledge in new situations, rendering students unable to proficiently design experiments for the field of biotechnology. Therefore, it is recommended that changes are made in the current curricula that focus on teaching metacognitive conditional knowledge to students in order to reach the goals of science education that students acquire the knowledge, skills and attitude to perform scientific research.

Key-words: *Undergraduates; Problem solving; Scaffolding; Metacognition; Biology education; Designing experiments; Evaluation study*

Introduction

An important aim of science education at university level is to stimulate students to acquire the knowledge, skills and attitude needed to perform scientific research. However, according to Van der Rijst (2007), science curricula in bachelor studies fall short in reaching these aims. Goedhart (2007) argues that one of the reasons for this is the way practicums are performed. They often focus on teaching students detailed techniques through close-ended inquiry, often dubbed "cookbook" practicums for their recipe-like structure. Kirschner (1991) confirms that through close-ended inquiry in practicums students are not stimulated to reflect on new concepts that are presented to them, and are not able to incorporate the knowledge from those practicums into new situations.

Because of this, the bachelor's studies of the sciences at Utrecht University have experimented with incorporating more open-ended inquiry activities in their curricula. The goal of this is to fulfil the aim that students acquire the knowledge, skills and attitude to perform research (Boerwinkel, 2014). However, these activities often lack the explication of what is learned by the student during these activities (D.J. Boerwinkel, personal communication, March 31, 2014). This means that, for example, newly acquired strategies or heuristic abilities are not incorporated in the student's metacognition, which is required in order for the learner to use them in new situations (Schraw, 1998).

Postma (2013) performed a preliminary study in order to explore the characteristics and opportunities of an educational approach to guide first-year undergraduate students in the field of biology in designing experiments for molecular biology. In the study, students were presented with a problem-solving approach, based on a series of techniques used in molecular biology, as can be seen in figure 1.

Experiments in biotechnology typically follow a similar research method to collect data for answering the research question. Several techniques are used in order to manipulate the experiment's starting material to obtain this data (Postma, 2013). For example, a sample of a bodily tissue can be the starting material. Techniques such as isolating DNA, a Polymerase Chain Reaction and screening techniques can then be used, eventually resulting in a specific gene that can serve as an end product and be used for analysis.

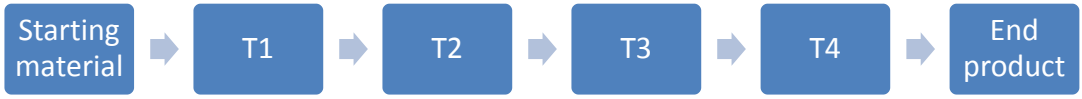

Figure 1. Schematic presentation of a designed experiment. From the initial material used in the experiment ('starting material') several techniques ("T1","T2", etc.) can be used in order to collect end data that can be used for analysis ("end product"). Image based on Postma (2013).

According to Postma (2013) these techniques all have the same basic features. Every technique requires an input of materials in order to generate a certain output, while the technique itself serves as the throughput. The output of the used technique may then serve as the input of the subsequent technique. This chain of steps has resulted in an input/output-model usable in teaching experiment design.

The theoretical foundation for the input/output-model lies in the use of problem solving strategies, aiming to let student reflect on the different aspects of designing an experiment, including the starting materials and outcomes of each step in a work plan. The strategies chosen as the basis of the model are general problem solving strategies as they can be considered intuitive by nature, and are often already a part of a person's metacognition. Therefore, students should be encouraged to use these intuitive strategies in an educational context to help them integrate these strategies into their metacognitive skills in experiment design (Postma, 2013; Schraw, 1998).

The model designed by Postma (2013) was used in a hypothetical learning trajectory (HLT) and tested in a small-scale extra-curricular lesson. In a series of learning activities students were scaffolded during learning to use the model that was designed in order to activate the student's intuitive problem solving strategies. Over the course of several learning activities the amount of scaffolding was gradually reduced, eventually leading to students working independently with Postma's model of input/output chains (Postma, 2013). The study showed that the lesson helps students to adopt a self-directed approach when designing the research method for a hypothetical experiment. When scaffolding eventually is removed, students tend to take over the approach posed in the HLT (Postma, 2013).

These findings have led to a change in the first-year biotechnology course of the bachelor study of biology at Utrecht University, the Netherlands. Based on the model by Postma (2013) an assignment was created by the coordinator of the first-year 'Biotechnology' course. The assignment, which can be found in appendix A,

posed students an adapted version of Postma's input/output-model, which can be seen in table 1. The aim of the assignment was to let students hypothetically design a genetically enhanced bacterium which had useful properties for industrial, medical or scientific purposes. With help of the model, students needed to write a work plan for the bacterium to be engineered. To do so, starting materials in the form of vectors, promoters and genes with specific properties were chosen by the student and a set of protocols containing biotechnological techniques were available to write the work plan.

Table 1: Input/output-model as used in the assignment of the biotechnology course. Students were required to write down input materials, the chosen protocol and biotechnological technique, and the resulting output. In addition, students had to define the time that was needed to perform a certain technique.

Step	Input	Protocol	Output	Allotted Time
1	- E. coli DH5α and plasmid pMC1 - medium containing ampicillin	Protocol 5 - growing bacteria	grown culture of E. coli with plasmid pMC1	24h
2	- Culture of E. coli and plasmid pMC1	Protocol 3 - Isolation of plasmids	Isolated plasmids	3h
…				

The assignment used in the biotechnology course differs from the study by Postma (2013). The assignment did not extensively scaffold students in using the model in the same way as Postma (2013) did. The three phases of scaffolding, 'building up', 'fading' and 'handing over to independence', were not presented to the students. It could be that the absence of this extensive scaffolding process in the course's assignment has led to students failing to use intuitive problem solving strategies in combination with the input/output-model. The consequence of this could be that these strategies and the model were not integrated in the students' metacognition. It is therefore unknown if the model and its intentions were properly understood by the students. It is also not known if the model is implemented in the students' metacognitive procedural and/or conditional knowledge, which is necessary for the student in order to remember the model and use it in other situations (Schraw, 1998).

Since the major goal of the input/output-model is to guide students in writing a work plan, as well as reflecting on techniques, steps and outcomes of an experiment, it is important to evaluate whether these goals were reached during the course's assignment. By assessing if the input/output-model has reached the students' metacognition during the biotechnology assignment, conclusions can be drawn whether the absence of an extensive scaffolding process prohibits students from learning the model and integrating it with their intuitive problem solving strategies. The results of this assessment may lead to criteria that describe the amount of guidance needed in science education in order to reach the aim of teaching the knowledge, skills and attitude necessary for undergraduate students to do research.

Theoretical Framework

In order to assess the learning outcomes of the biotechnology course's assignment literature about the aims of science education in the Netherlands, inquiry, inquiry-based learning, scaffolding and metacognition has been consulted. In this section the rationale is presented that has been the basis for the framework which assessed the learning outcomes.

Aims of science education regarding scientific research

Van der Valk & Van Soest (2004) have explicated the aims of science education regarding teaching students how to perform a scientific research. The authors define these aims in the form of three components that are important to perform scientific research, which can be seen in table 2. The first component, research skills, consists of procedural skills such as formulating research questions, setting up an experiment and writing reports. The second component consists of knowledge on the process doing research. It means that the student knows the definitions of research components such as a hypothesis, as well as the conception of the epistemological side of science. The third component that is described is the scientific attitude. Aspects of this, defined by Van der Valk & van Soest, are "wanting to know", "wanting to share" and having a "critical view" (Van der Valk & Van Soest, 2004).

While all these components and aspects are essential for learning to perform research, this study will focus on those that concern designing experiments. When designing an experiment, it is important to choose a research method that will yield data in order to give an answer to a research question. Aspects of Van der Valk & Van Soest that can be linked to this are general skills, general knowledge of the process of doing research and a critical view. These aspects will therefore be a focus in this study.

Table 2: Components of scientific research, according to Van der Valk & Van Soest (2004).

Component	**Aspects**	**Example**
Research skills	General skills	Formulating a research question, experiment design
	Domain specific skills	Using certain equipment
Knowledge on the process of doing research	General knowledge	Definitions of hypothesis and research question
	Domain specific knowledge	The ability to distinguish different types of research, such as a describing- or experimental research
	Epistemological side of science	Knowing that knowledge is not definite and is subject to review and change
Scientific attitude	Wanting to know	Natural curiosity and intrinsic motivation
	Wanting to share	Seeking contact with peers and discussing actions
	Critical view	Judging literature or components of a research

Inquiry

To reach the aims concerning experiment design, a strategy is required that suits the way these goals are reached in an educational environment. One of these strategies is inquiry (Anderson, 2002; Hmelo-Silver, Golan Duncan, & Chinn, 2007). Inquiry as a concept is difficult to define. Over the last decades the way inquiry is used, interpreted and defined is described in many different ways (Abd-El-Khalick, et al., 2004; Anderson, 2002; Edelson, Gordin, & Pea, 1999; Hmelo-Silver, Golan Duncan, & Chinn, 2007; Marx, et al., 2004; NRC, 2002). The National Research Council (NRC) (2002), states that “students who use inquiry to learn science engage in many of the same activities and thinking processes as scientists who are seeking to expand human knowledge of the natural world” (p. 1).

To divide the different goals of inquiry, Abd-El-Khalick et al. (2004) and Hodson (2003) have categorized the several forms of inquiry (table 2). Abd-El-Khalick et al. divide the concept into ‘inquiry as means’ and ‘inquiry as ends’. In the first category, inquiry as means intends to help students develop an understanding of science content, such as conceptual knowledge. Inquiry as ends refers to inquiry as an instructional outcome:

"Students learn to do inquiry in the context of science content and develop epistemological understandings about NOS and the development of scientific knowledge, as well as relevant inquiry skills" (Abd-El-Khalick, et al., 2004, p. 398).

In addition to these definitions, Hodson (2003) poses three categories that are similar to those proposed by Abd-El-Khalick et al (2004): 'learning science', 'doing science' and 'learning about science'. 'Learning science' can be defined as gaining conceptual knowledge on science. 'Doing science' is defined as "engaging in and developing expertise in scientific inquiry and problem solving" (p. 658), which can be seen as the development of the skills needed to perform inquiry. Learning about science can be seen as learning about the epistemology of science and is described by Hodson as "developing and understanding of the nature and methods of science and technology, an awareness of the complex interactions among science, technology, society and environment, and a sensitivity to the personal, social, and ethical implications of particular technologies" (Hodson, 2003, p. 658).

The categories defined by Abd-El-Khalik et al. (2004) and Hodson (2003) show overlap, where inquiry as means and learning science show parallels. Doing science and learning about science can be grouped with inquiry as ends, as is shown in table 3.

Table 3: Depiction of the different categories of inquiry as defined by Abd-El-Khalik et al. (2004) and Hodson (2003), as well as the parallel between the two. In addition, brief aspects of the categories are shown. Highlighted are categories that will be used in this study.

	Category of inquiry		
Abd-El-Khalick et al. (2004)	Inquiry as means	Inquiry as ends	
Hodson (2003)	Learning science	Doing science	Learning about science
Aspects of category	Conceptual knowledge	Engaging in science, developing skills	Understanding the nature of science and its epistemology

The aspects of the categories show that doing science focusses on developing skills and abilities that are needed to perform scientific inquiry. In order to teach students the aims of doing research that were defined by Van der Valk & Van Soest (2004), inquiry-based methods that are part of the 'inquiry as ends' and 'doing science' could prove useful, as they cover he same subjects as the aims of science education that focus on scientific research.

Therefore, this study will focus on the use of inquiry as ends during the analysis of the assignment used in the biotechnology course, as well as the design of the evaluation tool used for this study.

Inquiry-based learning and problem-solving

Inquiry learning (IL), more widely known as inquiry-based learning, is a learning strategy where students acquire new knowledge through posing questions and learning –or activating- problem-solving strategies, rather than just learning facts. It asks an active engagement from the student and the questions asked lead to developing knowledge on the questions answered (Anderson, 2002). An example of IL is a scenario in which problems are in need of identification by the students. In order to solve the problem, requisite knowledge is necessary. This may be existing or new knowledge, defined by the student (Hutchings, 2007). To give an example from the field of biotechnology, an assignment can be considered that poses a student a problem or question about a disease in humans caused by a mutation. In order to solve the problem, students need to acquire new knowledge on concepts such as mutations, genes and other related concepts that underlie the theoretical part of the assignment. The advantage of this is that the newly acquired knowledge consolidates better than knowledge which is just presented to the student (Hickey, Kindfield, Horwitz, & Christie, 1999). Because of this, IL could be useful as a strategy to let students engage in science.

One form of inquiry is through the use of problem-solving strategies. In general such a strategy consists of an authentic problem posed to the student, and the solving process in which the student formulates an answer to the problem (Dhillon, 1998). According to Leonard, Dufresne & Mestre (1996), a correct problem-solving strategy consists of three parts: “(1) the major principle(s) or concept(s) that can be applied to solve the problem; (2) a justification for why the principle(s) or concept(s) can be applied; and (3) a procedure by which the principle(s) or concepts can be applied to arrive at a solution” (p. 1496).

Postma (2013) described two problem-solving strategies used in teaching the input/output-model: problem decomposition and means-end analysis. In problem decomposition, a problem that is deemed to be too large to solve at once is analysed and broken-up into smaller sub questions, which can be solved on their own in order to solve the overarching problem.

In a means-end analysis the goal is to assess the current knowledge state and goal state, followed up by seeking and using new operators to close the difference between the two states (Dhillon (1998); Gick (1986) & Jonassen (1997) in Postma (2013)).

The two problem-solving strategies used by Postma consist of the three parts defined by Leonard, Dufresne & Mestre (1996). During problem decomposition, the major principle applied is breaking up a large problem into smaller problems. These small problems are the individual biotechnological techniques, presented to the students in the form of protocols that consist of the procedure of the biotechnological techniques in question. The other problem-solving strategy, means-end analysis applies its major principle to these protocols: using the current knowledge state and goal state and close the gap between the two. The protocols are analysed by their input and output. The input of a technique or protocol can then be chained to the output of another protocol. What follows is a chain of protocols/techniques that lead from the current state to the goal state (i.e. a research method that provides data for a research question).

The two problem-solving strategies together provide for the other two parts that define a good strategy. The justification of the use of the strategies can be found in the way they can be used to write a work plan that fills the gap between the current state and the goal state. The procedure that the strategies can be applied to is writing the work plan itself.

The input/output-model makes extensive use of the two problem-solving strategies (problem decomposition and means-end analysis), which are intuitive by nature and are as such already a part of the student's metacognition. The goal of the input/output-model is to integrate these intuitive problem solving strategies in the student's procedural and metacognitive conditional knowledge with experiment design. Because of the extensive use of the two strategies by Postma (2013) this study will use these strategies to design the HLT in retrospect for the biotechnology course's assignment, as well as the evaluation tool.

Scaffolding

Scaffolding is a teaching strategy that emanated from the constructivist learning theory (Greening, 1998), and is based on cognitive apprenticeship, which in itself is based on the principles of traditional apprenticeship.

Traditional apprenticeship can be defined through the example of learning a specific trade from an expert, such as tailoring (Lave, 1977). Cognitive apprenticeship can therefore be defined as a teaching strategy where a student learns concepts taught by an expert (Brown, Collins, & Duguid, 1988).

This means that students learn through the experiences of the expert, using constructivist principles. The experience of the expert are provided to the student, leading to assimilation of new knowledge in the students' existing framework of knowledge (Woolfolk, Hughes, & Walkup, 2013)

During cognitive apprenticeship, an emphasis on two things can be seen. Firstly, cognitive apprenticeship embodies the fact that the focus is on learning through guided experience on a cognitive and metacognitive level, rather than physical skills and processes. Secondly, the expert primarily aims to teach the student the process he or she uses to handle complex tasks. Where factual knowledge is concerned, cognitive apprenticeship uses this in the context of the task that is performed (Collins, Brown, & Newman, 1987). In short, cognitive apprenticeship can be seen as a strategy where a teacher is a knowledgeable source of information. The goal of the teacher is to transfer this information to his or her students by guiding them through tasks. One way to guide the students is through scaffolding.

Scaffolding is best defined as the help to a learner that is tailored to that learner's needs in achieving his or her goals of that moment. The best scaffolding provides this help in a way that contributes to learning without intruding in, or taking over, the learning process (Sawyer, 2006). Mostly, scaffolding is used during complex tasks, such as inquiry learning or problem solving (Hmelo-Silver, Golan Duncan, & Chinn, 2007). It helps students engage in sense making, managing investigations and problem-solving processes, often through encouraging students to articulate on their thinking process and to reflect on their learning (Quintana, et al., 2004).

In general, three phases are considered during the whole scaffolding process: 'building up', 'fading' and 'handing over to independence'. The 'building up' phase is a metaphor for building up actual scaffolding and describes the extensive guiding of the student during an (inquiry based) assignment. In time, as the student progresses, the amount of scaffolding is eventually decreased until no more scaffolding is needed at all; a process is called 'fading' (Jackson, Krajcik, & Soloway, 1998).

When ‘fading’ as a phase is completed the students are asked to independently complete the task or assignment. Because of this the last phase of scaffolding is named ‘handing over to independence’.

Scaffolding is part of the theory of cognitive apprenticeship, which is in itself based on traditional apprenticeship. The way scaffolding can be used in teaching activities depends on the type of strategy that is used. One strategy, posed by Hmelo-Silver & Barrows (2006) Shows that scaffolding is performed by asking students questions to encourage them and help them to explain their thinking patterns to help build a casual explanation. This use of scaffolding can therefore be named a reasoning strategy (Hmelo-Silver, Golan Duncan, & Chinn, 2007). Another example of a reasoning strategy is through the use of work sheets that provide self-directional guidance for the students to solve a given problem (Bell P. , 1997; Toth, Suthers, & Lesgold, 2002).

The latter is used in the study by Postma (2013), as well as the assignment designed for the biotechnology course. The difference between the two, however, is that during the study of Postma (2013) students were explicitly led through the three phases of scaffolding. After several tasks, scaffolding was gradually faded, before handing the independence over to the student. This was not the case during the biotechnology course’s assignment, leaving the question whether the input/output-model as a strategy has become a part of the students’ metacognitive knowledge.

Metacognition

The term ‘metacognition’ first emanated in the field of psychology during the 1970s. One of the founders of the term ‘metacognition’ is John Flavell. Metacognition as a concept is hard to define, but is often described as “thinking about thinking” (Livingstone, 2003). Mostly metacognition is used to describe a person’s knowledge about when to use particular strategies for learning or for problem solving (Metcalfe & Shimamura, 1994). This means that, for example, newly acquired strategies or heuristic abilities are incorporated in the student’s metacognition, which is required in order for the learner to use them in new situations (Schraw, 1998).

Schraw (1998) makes the distinction between two components of metacognition: (a) ‘knowledge of cognition’ and (b) ‘regulation of cognition’. The first refers to what individuals know about their own cognition or about cognition in general. The latter refers to a set of activities that help students control their learning.

Knowledge of cognition as a component contains three kinds of cognitive awareness: declarative (i), procedural (ii) and conditional (iii) knowledge (Jacobs & Paris, 1987).

i. Declarative knowledge includes knowledge of oneself as a learner and what influences the process. As an example, adults know better what they have learned and how they did it when compared to a child (Baker, 1989 in Schraw, 1998).

ii. Procedural knowledge refers to knowledge about doing things. Much of this knowledge is represented as heuristics and strategies. A high degree of procedural knowledge means that a person performs tasks more automatically and uses qualitatively different strategies to solve problems (Glaser & Chi, 1988 in Schraw, 1998).

iii. Lastly, conditional knowledge is knowledge on when and why to use certain declarative and procedural knowledge (Garner, 1990). An example of this is a student who knows when to rehearse which information for a test (Reynolds, 1992 in Schraw, 1998).

Regulation of cognition refers to a set of skills that help students control learning. These skills aid the performance of learning, including better use of attentional resources and better use of known strategies (Schraw, 1998). There are many different regulatory skills, aimed at specific learning situations. However, Jacobs & Paris (1987) describe three main skills that are included in most regulatory skills: planning, monitoring and evaluation.

The input/output-model of Postma (2013) aims to regulate the knowledge of cognition of the student by using the intuitive problem solving strategies already learned by the student. By doing so, known strategies such as problem decomposition and means-end analysis are integrated in the student's metacognition needed to design experiments. The students acquire a high degree of metacognitive knowledge regarding the task, making it useful when designing experiments in other situations, such as experiments in other courses.

This study will focus on assessing knowledge of cognition, because this component of the student's metacognition deals with learned problem-solving strategies and how to use them in new situations (Schraw, 1998). Therefore, it is necessary to assess whether the model is indeed part of the students' metacognition after completing the assignment of the biotechnology course.

Research Question

The aim of this study is to evaluate the assignment that has been developed for the first-year bachelor course 'Biotechnology' of the study of biology at Utrecht University, the Netherlands. It will be assessed whether the input/output-model, as used in the assignment, has sufficiently been implemented in the procedural- and conditional knowledge of the students' metacognition. Therefore, the main research question is: *to what extent does a problem-solving approach with minimal scaffolding contribute to undergraduate students' metacognitive knowledge on designing experiments?*

To answer this research question the following sub questions are formulated:

- To what extent are undergraduate students' intuitive problem-solving strategies integrated in their metacognitive procedural knowledge regarding experiment design?
- To what extent is the proposed input/output-model part of undergraduate students' metacognitive conditional knowledge?

Methodology

Evaluative research

In order to answer the research question and its sub questions, this study was divided into two phases, the analysis phase and the evaluative phase (figure 2).

In the analysis phase existing data sources from the biotechnology course were collected, i.e. the course assignment, written by the course's coordinator, and students' answer sheets of the course's assignment. These sources were used to analyse whether students were able to work with the input/output-model, and if the problem-solving strategies could be part of the students' metacognitive knowledge on experiment design.

In the evaluative phase an assignment was designed to assess the participants' metacognitive knowledge, followed up by a semi-structured interview to get more insight in the students' metacognition.

In the following section the different materials and methods will be discussed. An overview of the different materials and their relations can be seen in figure 2.

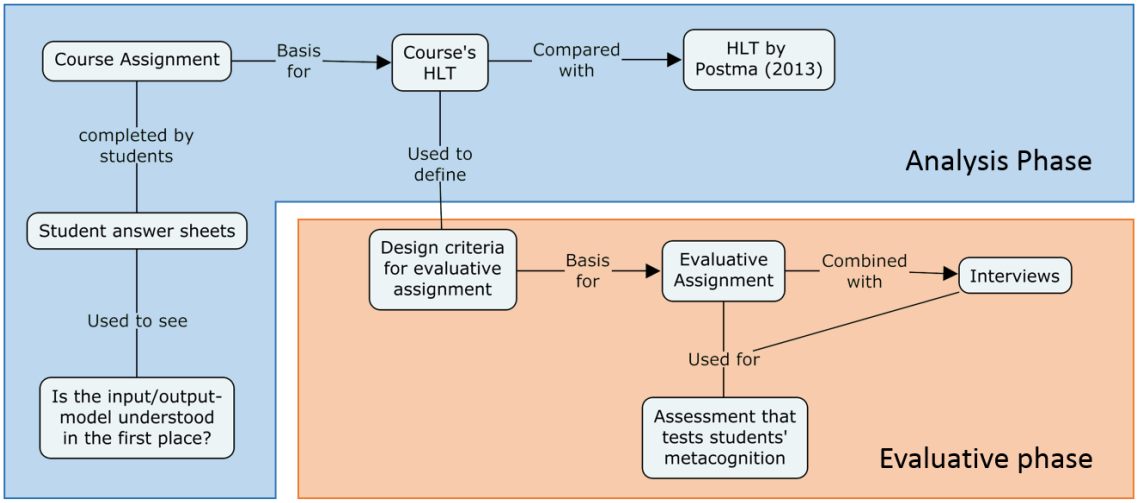

Figure 2 Schematic overview of the different data sources and research methods used in this study. The different sources and methods are divided into two research phases: the analysis phase and evaluative phase.

Sample

All first-year undergraduate biology students of Utrecht University, the Netherlands attended the course 'biotechnology' in the third semester, February- April 2014. Seven students (3 male, 4 female) ages ranging from eighteen-nineteen voluntarily participated in the evaluative assignment and subsequent interview.

At first eight students would be participating. However, one student (female, nineteen years old) dropped out due to personal circumstances. All participants were enrolled in the course for the first time. It was also the first time for all participants to be enrolled in university level education.

The participants attended the study in couples. Since one student dropped out, one participant, student 5, participated in the study individually. An overview of the couples of students participating can be seen in table 4.

Table 4: Overview of the couples and students participating in the study, with gender and age shown.

Couple number	**Student number (sex, age)**
Couple 1	Student 1 (M, 18 y/o)
	Student 2 (M, 18 y/o)
Couple 2	Student 3 (F, 18 y/o)
	Student 4 (M, 19 y/o)
Couple 3	Student 5 (F, 19 y/o)
Couple 4	Student 6 (F, 19 y/o)
	Student 7 (F, 18 y/o)

Analysis phase

In the analysis phase data sources were collected from the biotechnology course and analysed. The course's assignment (see appendix A) was used to create a hypothetical learning trajectory (HLT) in retrospect in order to assess the assignment's learning goals, and to inventorise in which way students were scaffolded during the assignment. The answer sheets were used to analyse whether the students were able to work with the input/output-model during the biotechnology course. This way it was made sure that the input/output-model's problem-solving strategies could be part of the students' metacognition.

Design of the HLT

The HLT was designed in retrospect for the course's assignment since none was made beforehand. An HLT consists of the assignment's learning activities, goals and learning expectations. The learning activities of the HLT were described using the assignment sheets made by the course's coordinator.

The way scaffolding was provided to the students was inventorised for each learning activity to compare the difference in scaffolding between this assignment and the initial design by Postma (2013). During the analysis of the way scaffolding was used during the course's assignment, the distinction was made between the three phases of scaffolding (building up, fading and handing over to independence). A comparison between the HLT described in retrospect and the HLT described by Postma (2013) can be found in appendix B.

After the initial design, the HLT's was discussed with the course's coordinator in order to make sure the assignment's learning goals and intentions corresponded with the coordinator's intentions.

The HLT formed the basis for criteria used to design the evaluative assignment useful to assess the students' metacognition. The following criteria were distilled from the HLT:

- The student is able to write a work plan for a biotechnological experiment using the input/output-model and a given set of protocols.
- The student is able to reflect on their own work plan by checking whether the protocols are all linked by their input and output.
- The student is able to use the theoretical concepts taught during the course's lectures in the assignment.

These criteria were used to design the evaluative assignment

Analysis of the answer sheets of the course's assignment.

The course's assignment's answer sheets of the students participating in this study were collected and used to assess whether the students correctly used the input/output-model during the course's assignment. This was done in order to make sure that the evaluation tested the students on their recollection of the model as was taught in the assignment.

The answer sheets of six of the seven participants were available for analysis. During the biotechnology course the assignment was completed in groups of five. Since most of the participants also worked together during the biotechnology assignment there were four answer sheets available for analysis.

Grades were given by the course's teaching assistance and verified by the course's coordinator. Grades were based on three aspects: originality, applicability and quality of the protocol.

To assess whether students had a good understanding of the input/output-model in the course's assignment, the grades of the quality of the assignment were analysed primarily.

Evaluative phase

During the evaluative phase the evaluative assignment was designed according to the earlier mentioned design criteria and used to assess the participants' knowledge of cognition. The participants were interviewed directly after they completed the evaluative assignment.

Design of the evaluative assignment

A Dutch version of the evaluative assignment can be found in appendix C. The evaluative assignment was designed to look similar to the course's assignment in terms of general design and layout (i.e. write a work plan using a given set of protocols) to make sure the student would be able to trigger their conditional knowledge. To test the participants for their procedural and conditional knowledge no scaffolding was provided and no mention was made of the input/output-model, so results would be solely based on the students' knowledge of cognition.

To make sure that the assignment was theoretically correct a biological topic used in the post test of the study by Postma (2013) was used for the evaluative assignment. The subject of the assignment was based on a topic that was taught during the biotechnology course. Students were asked to design a workplan for a hypothetical experiment that aimed to create a cDNA bank from isolated tissue from *Folsomia candida*. In addition, personal communication with the course's coordinator took place to ensure that the assignment was theoretically sound.

The assignment consisted of a main problem sheet on which the problem was posed to the participants and included a back story that presented context leading up to the problem. In addition, students were provided with answer sheets and six protocols containing biotechnological techniques; five of which were needed to complete the assignment correctly. This was done to force students into critically analysing the protocols and their theoretical background. If deemed necessary, the participants also had a textbook available that was used in the biotechnology course to look up concepts and/or procedures to make sure that they were not hampered by a lack of conceptual knowledge on the assignments subject.

To stimulate the thinking process and invoke discussion useful to record as a data source, participants completed the assignment in couples.

Interview

Together with the evaluative assignment an interview was set up to be able to let students elaborate on their performance and/or to ask the students questions on possible gaps in their reasoning. Interviews were semi-structured and were held directly after the participants completed the evaluative assignment. A backbone for the interviews containing pre-composed question lists can be found in appendix D.

The questions in the interview were chosen to help determine the participants' metacognitive knowledge. For example, when the assignment was not completed correctly, the interview would help point out which type of metacognitive knowledge was the bottleneck. Examples of these questions and the type of knowledge they were linked to can be found in table 5.

During the interview the participants were shown a copy of the input/output-model, the same one used in the course's assignment. They were then asked to explain what the scheme was, what it could be used for and what the benefits were of using the scheme. By doing so, the procedural knowledge of the participant was tested.

Table 5: Examples of questions asked in the interview to assess the participants' metacognitive knowledge.

Question asked	**Type of knowledge assessed**	**Indication**
Did you learn a certain strategy to complete the assignment?	Conditional knowledge	Negative answer indicates a lack or deficit in conditional knowledge
Can you remember the way you had to write the work plan during the course?	Conditional knowledge	Negative answer indicates a lack in conditional knowledge
Do you recognise the scheme I show you know?	Procedural knowledge	Negative answer suggests that there is a lack in procedural knowledge. Positive answer suggest students only lacks in conditional knowledge
Can you explain how this scheme works?	Procedural knowledge	Negative answer suggests a lack in procedural knowledge.

Data collection of the evaluative assignment and interview took place in the period of mid-June to July 1st, 2014; seven to ten weeks after the end of the biotechnology course. During the evaluative assignment and interview participants were videotaped to capture discussions. The first author was present to guide students where necessary and to lead the interview.

Transcription and coding of evaluative assignment and interview

Discussions captured on video during the evaluative assignment and subsequent interview were transcribed and coded using NVivo 10 for Windows PC (QSR International, 2012).

The labels used for coding the transcripts can be found in appendix E. The following criteria were described that were assessed during the evaluation phase:

- Understanding of theoretical concepts;
- Use of problem decomposition;
- Use of means-end analyses;
- Signs of metacognitive conditional knowledge;
- Understanding of the intentions of the input/output-model.

To distinguish between different ways of meeting a certain criterion, several actions were described in detail. These actions describe certain behaviour of the participant that suggested he or she met a particular criterion. Where possible, the actions were described on a scale of several levels to decrease the number of borderline cases and increase reliability between the first and second coder. An example of these actions can be seen in table 6.

Table 6: Example of a criterion assed during the coding of the evaluative assignment and interview. Several actions distinguish between different levels of meeting the criterion. Each action has a corresponding label used during coding.

Criterion	Action	Label
Use of means-end analysis (part of metacognitive procedural knowledge)	Students note step-wise procedure of experiment.	MEA.01
	Students try to chain protocols by their respective input/output.	MEA.02
	Students reflect on their work in order to find gaps in their chain of protocols.	MEA.03
	Students correct for gaps in their work after reflecting on their results.	MEA.04

During coding striking quotes were labelled that showed signs of the use of the input/output-model and its metacognitive procedural knowledge, including means-end analysis and problem decomposition strategies. In addition, quotes were labelled that showed signs of metacognitive conditional knowledge, such as recognizing the assignment from the biotechnology course or actively trying to use the solving strategy taught in the biotechnology assignment.

Coding was also done by an independent second coder for reliability purposes. The second coder used the same scheme of criteria and corresponding actions to code the complete transcripts of the evaluative assignments and interviews of all participants.

All quotes and/or actions that were labelled by either the first coder, second coder or both were summed up. An example of this is shown in figure 3. The figure shows an excerpt of the list of quotes from the complete transcript of one of the couples. Significant quotes were labelled by the coders and the correspondence between these quotes were calculated.

The labels that corresponded between the first and second coder were divided by the total number of quotes that were labelled by either one or both coders. In the example found in figure 3, the total number of quotes is five, while the number of corresponding quotes is 4, which would give a rate of correspondence of 80%.

The complete rate of correspondence between the first and second coder in all transcripts was 77%.

	Timespan	Content	Speaker	Code	2nd_Coder
38	9:11,7 - 9:24,4	Oh, hier moet je al totaal geisoleerd RNA toevoegen. Dus het is handig...je moet het eerst isoleren en daarna zuiveren	student 4	MEA.02	MEA.03
39	9:24,4 - 9:31,7	Dat lijkt me een meer logische volgorde. Ok.	student 3	mea.03	MEA.03
40	9:31,7 - 9:38,0	Hier is het ingangspunt dus een weefsel. En we starten ook met een weefsel.	student 4	MEA.02	MEA.03
41	9:38,0 - 9:40,9	Ja. Ok. "Stap 1".	student 3		
42	9:40,9 - 9:44,4	Protocol 3	student 4		
43	9:44,4 - 9:53,3	Dit voelt net gewoon aan als dat ene projectje van 'maak je eigen bacterie', dat we ook gewoon protocollen oplazen.	student 4	MCK.01	MCK.01
44	9:53,3 - 9:57,3	Ja, toen zat ik nog in de stof met m'n hoofd, nu ben ik er al weer uit.	student 3		
45	9:57,3 - 10:27,9	Ik had bijna hetzelfde. Waarom niet 'DNA isolatie' alsnog? Want hier haal je DNA uit het weefsel, alleen dat heb je niet nodig want je	student 4	MEA.03	MEA.03

Figure 3: Excerpt from one of the transcripts of the evaluative assignment. The transcript shows the list of quotes by the participants, students 3 and 4. The last two columns show labels given to the quotes by either the first or second coder. Correspondence between these labels were calculated.

Results

The results section is divided up between the two phases of this study. The results of the analysis phase are shown per data source. Results from the evaluative phase are shown according to the different types of metacognition that were assessed.

Analysis phase

HLT of the course's assignment

A complete version of the HLT that was described in retrospect for the biotechnology course's assignment can be found in table 6. The HLT consists of three learning activities. The first activity asks of the student to read the assignment and its questions. This includes an overview of the concept of bio bricks and how they are built into vectors. The second learning activity consists of choosing the components necessary to enhance the *Escherichia coli* bacterium, including plasmids, vectors, promoters and genes that have different abilities described on extensive lists. After choosing the desired components students are asked to describe how their enhanced bacterium works and give arguments for the bacterium's purpose. The third learning activity consists of writing the work plan to the experiment of enhancing the bacterium by means of the input/output-model. Students were asked to provide a scheme consisting of the input and output of each technique, as well as the time it takes to perform the step in the work plan. The techniques were provided in a set of protocols, some of which were not necessary for a correct work plan. Therefore students were forced to make informed choices for the protocols to be used. To stimulate this further the order of the protocols was scrambled.

Distilled from the expected learning outcomes per learning activity, as well as from personal communication with the course's coordinator, the following learning goals could be formulated for the assignment:

1. The student can work with, and give an explanation on, the concepts of Bio bricks', 'restriction sites', 'cloning' and relating concepts as were covered in the lectures.
2. The student can provide solid arguments to justify the relevance for the need of a scientific research.
3. The student is able to write a work plan based on different biotechnological techniques, by use of the input/output-model.

4. The student is able to reflect on a self-written work plan, find gaps in the chain of techniques described and is able to correct for these gaps.

Scaffolding provided to the students in, and during, the assignment is found in the first and last learning activity. It is mostly provided verbally and visually using text and images respectively. During the third learning activity the teacher was also available to answer questions. Verbal scaffolding was mostly found in the introductory text which included a step-by-step explanation of how the assignment should be completed and how the input/output-model should be filled out schematically. Visual scaffolding was provided by showing the input/output-model's scheme. The first step of the work plan was filled out as an example of how to chain the protocols provided with the assignment.

Table 7: Hypothetical Learning Trajectory (HLT) of the course's assignment (appendix A). The phase of scaffolding corresponds to the phase of scaffolding defined by Postma (2013). The problem solving element shows the problem solving strategy that the student needs to apply in that particular learning activity. The way the student is scaffolded is shown per learning activity. Verbal scaffolding means the student was guided through instructions by teachers of in the assignment's text. Visual scaffolding is given to the student in the form of images or schemes.

Phase of scaffolding	Problem Solving element	Learning activity	Scaffolding		Student activity	Hypothesised learning result
			Verbal	Visual		
1. Building up the scaffold	Introducing the operators in the problem space.	**LA1** Preparation The topic and assignment are presented through the text of the assignment. Students will familiarise themselves with the general concepts and goals.	Introductory text about the research topic and method, including step-by-step guidelines to complete the assignment.	Images and schematics of the 'Bio brick'-system. Visual representation of the input/output-model	Student reads the contents of the assignment.	Student understands the topic (Genetically modifying an *E. coli* bacterium) and recalls the concepts 'Bio bricks', 'restriction sites', 'cloning' and relating concepts as was covered during lectures.
No scaffolding	None	**LA2** Filling in context Students are asked to design an *E. coli* with an enhanced promoter and gene/operon, giving it a new (commercially useful) ability. Different promoters and genes/operons can be chosen from extensive list. A suitable plasmid needs to be chosen as well	None	None	Student picks a plasmid, promoter and gene(s) from the list and describes the reason of choice on the answer sheet provided.	Student gains insight in the way new research is formulated. Student can provide solid arguments to justify a research.

3. Handing over to indepen-dence	Applying problem-decomposition and means-end analysis.	LA3 Designing the experiment Students are asked to write a work plan using the input/output-model according to the scheme presented in the guidelines. The different steps needed to design the experiment must be found in several protocols provided, each containing a biotechnological technique.	Step-by-step guidelines, including an explanation of the input/output-scheme shown. Protocols containing the biotechnological techniques to write the work plan. Teacher available for questions.	Scheme of the input/output-model, shown in the assignment's guidelines and on the provided answer sheet.	Students uses description of the chosen plasmid, bio bricks etc. and searches for the correct protocols, guided by the framework of the input/output-model: Describe input, find the suiting protocol, describe output, find next protocol etc.	Student understands that a research method consists of several techniques and that one technique provides the starting point for the next. Student will reflect on work plan to see gaps in research method and is able to correct them.

Comparison with Postma

To find out whether there were any differences between the scaffolding provided in the assignment and in the study by Postma (2013) their respective HLTs were compared. The HLT described by Postma, including overlap with the course's HLT can be found in appendix B2.

When comparing the HLTs it shows that the HLT by Postma is based on the three phases of scaffolding: building up, fading and handing over to independence. The course's HLT shows that during the introduction the first phase is established. The third phase of scaffolding can be found in filling out the work plan. The second phase, 'fading the scaffold', is not found in the course's assignment. Normally during this phase, scaffolding is gradually reduced until no more scaffolding is provided to the student and phase three is initiated.

When comparing the amount of learning activities in the two HLT's it is apparent that the HLT by Postma consists of three similar experiments. Students gradually engage more and more in each experiment until they are able to perform the experiment independently, corresponding with the three phases of scaffolding. In the course's HLT only one of these experiments is presented to the student.

Student performance on course's assignment

The grades given in the course for the assignment were relatively high with the participants scoring a 7,625 out of 10 on average. However, none of the work plans that were analysed were completely flawless. All work plans contained small mistakes that concerned the theoretical part of the assignment, such as the choice of restriction enzymes or vectors.

The chaining of protocols according to their respective input and output was done completely correct in two of the four protocols. The other two protocols both show one gap in the work plan's input/output chain. These findings suggest that in general students were able to perform means-end analyses and that there was a good understanding of how the input/output-model worked.

Evaluative phase

Student performance on evaluative assignment

General findings

An overview of the couple's performance can be found in table 8. Out of the four, two couples came up with the correct work plan for a cDNA bank. One couple left out one of the five necessary steps in the input/output chain. The participant who completed the assignment on her own performed the least, describing only two out of the five steps necessary for the work plan.

None of the couples reproduced the input/output-model exactly as it was shown in the course's assignment. However, two work plans show that participants tried to present their work plan in a similar way, using a chain-like layout for the work plan.

Table 8: Overview of the participants' performance on the evaluative assignment. The plus and minus signs show the degree of performance of each of the couples regarding certain criteria. Signs range from ++ (fully correct) to -- (not at all).

Couple	Correctness of work plan	No. of wrong/missing protocols	Reproduced I/O model	Reflection on work plan	Could explain I/O model during interview
1	+	1	--	+	++
2	++	0	+	++	++
3	-	3	--	-	+
4	++	0	+/-	+	++

Couple	Used problem decomposition	Used means-end analysis	Showed signs of conditional knowledge	Understanding of theoretical concepts
1	+	++	--	+
2	++	++	+/-	+
3	++	+	--	-
4	++	++	+/-	+

Understanding of the assignment's theoretical concepts

The participants' understanding of the theoretical concepts that were used in the assignment may have played a role in the way the work plan was completed. During the assignment a vast amount of time was spent by the participants on discussing theoretical aspects, such as the products that needed to be isolated from the starting material. This is shown in the following example.

Example 1 – Couple 4 (During assignment):

Student 6: *We need to make a cDNA bank.*
Student 7: *What was a cDNA bank again?*
Student 6: *It was a DNA bank, let's see. You convert RNA to DNA if I remember correctly. It's not a bank made from all of the DNA, just the DNA…*
Student 7: *You mean just the coding DNA?*
Student 6: *Yes, the ones used to translate into proteins.*
Student 7: *Sounds logical considering it's a C.*
<Student 6 reads the beginning of the protocol 'DNA isolation'>
Student 6: *(…) I think we should start with DNA isolation, to me that seems […] '…freeze tissue sample using blah blah blah'. Yes, that seems logical.*
Student 7: *But just now we went from RNA to DNA, right?*
Student 6: *But, with DNA you have to, no, wait.*

The example shows that the students struggled with coming to terms which material should be isolated from the tissue sample, which was the work plan's starting material. For a cDNA bank RNA should be isolated from the tissue, which means that the protocol 'DNA isolation' is useless for this experiment.

Another example of students struggling with some of the theoretical concepts is found in one of the protocols used later on in the assignment. The fourth protocol necessary for the work plan was named 'Priming of cDNA', and is used to modify just-made cDNA in a way that it can be used to clone into a vector. Apparently the word priming threw the participants of, as they linked it to the concept of 'primers', small pieces of RNA or DNA used as a starting point to replicate RNA- or DNA-strands. This can be seen in the two following examples.

Example 2 – Couple 2 (during assignment)

Student 3: *What's priming again?*
Student 4: *Priming is…*
Student 3: *Because how I find it in the text book they just synthesise cDNA and put it in a vector.*
<Student 4 refers to the protocol 'cDNA synthesis'>
Student 4: *And what is the result of this protocol?*
Student 3: *cDNA that's…well, just cDNA. The other one is the same. You've made the complementary DNA and want to store it.*
Student 4: *But priming cDNA. Doesn't that mean you have to secure it to make a bank or something?*
Student 3: *I don't know what is up with priming. It's a concept I completely forgot.*
Student 4: *(…) …then priming is just a piece of DNA secured on a larger strand in order for synthesis to take place. You put in polymerase etcetera. In a PCR machine you use lots of primers that are secured on single-stranded DNA in order for the PCR machine to replicate it. That's what primers are.*

Example 3 – Couple 1 (during assignment)

Student 1: *And then there's 'Priming of cDNA', 'cloning cDNA into a vector' and cDNA synthesis'. Looks like you start with priming.*
Student 2: *But it isn't cDNA yet, right?*
Student 1: *No, that's true*
Student 2: *During priming you make the second strand I guess. Somewhere it says reverse transcriptase.*
Student 1: *But the question is whether cDNA is RNA with another strand, or that you first make a DNA strand and then remove the RNA strand and replace it with a second cDNA (…). I think cDNA is two strands of DNA.*

These examples show that because participants were lacking in their knowledge on some of the concepts, they may have been hampered in their performance on the evaluative assignment.

Signs of participants' metacognitive procedural knowledge

The assessment of the participants' metacognitive procedural knowledge was divided up into analysing the transcripts for quotes that showed signs of participants using the 'problem decomposition' and 'means-end analysis' strategies.

Problem decomposition as a strategy was not found very clearly in the data. The cause for this is probably because both the course's assignment and evaluative assignment provided the students with a set of protocols.

These protocol are essentially a breakdown of the work plan into different components, which may be why participants did not actively try to break up the problem into smaller pieces. However, as can be seen in example 4, signs of problem decomposition were seen with student 5 (couple 3). Because she was overwhelmed by the amount of protocols, she used problem decomposition to try to get a better overview of the set of protocols. This was also done by couple 2 to inventorise the options given by the protocols, as seen in example 5.

Example 4 – Couple 3 (during assignment)

Student 5: *Here they already speak of cDNA. I presume that you would need to take a separate step to make cDNA; you can't do both mRNA and cDNA in a single step. That doesn't seem logical to me. Let's do this step-by-step. First we will do mRNA, then we will make cDNA.*

Example 5 – Couple 2 (during assignment)

Student 4: *Let's see what the protocols say. It would be easy if they were already in the right order of the work plan, but that is probably not the case.*

The use of means-end analysis by the participants was seen more clearly in the data of all couples. Examples 6 through 9 show moments of each couple trying to link protocols by their input and output. This means that students seem to be able to apply the intuitive problem solving strategies to the evaluative assignment.

Example 6 – Couple 1 (during assignment)

Student 1: *Yeah exactly. [The protocol] says you start with a tissue and [the assignment] says it as well. So, we begin with this one. And then this one because this one starts with '…the isolated RNA', then you purify the mRNA from it.*

Student 2: *Yeah, but then what's the result? What is the product of this one?*

Example 7 – Couple 2 (during assignment)

Student 4: *So, maybe we do need to do this step, you first synthesise cDNA and the use this step to have the right ends on it.*

Student 3: *But it doesn't clearly state 'we have cDNA here' and so forth.*

Student 4: *Then it's just a matter of finding out what this one ends with and what you should put into the next one.*

(…)

Student 4: *Ok, so we have mRNA. We put mRNA in [the protocol] and the result is cDNA.*

Example 8 – Couple 3 (during assignment)

Student 5: *Oh this one uses mRNA: '…prepare mRNA sample'. That's better because you've made the sample here and prepare it in this one so you can purify it. So therefore I should start with protocol number 3.*

Example 9 – Couple 4 (during assignment)

Student 6: *Oh! [the text book] says mRNA, so you'll need RNA isolation. Is there one that does that?*

Student 7: *Yes, this one. RNA, or is it mRNA? Which one do you need?*

Student 6: *I would guess mRNA, but I'm not sure. Doesn't it say what kind of RNA? It starts with a tissue, we can't start with anything else than a tissue.*

Student 7: *That's right. This one needs isolated RNA, so it has to come afterwards. If you need that one in the first place.*

Student 6: *In this one you turn mRNA into cDNA, so it's one of the latter ones.*

Signs of participants' metacognitive conditional knowledge

To assess whether the participants showed signs of having the metacognitive conditional knowledge that is necessary to reproduce the input/output-model the transcripts were analysed for quotes that met these conditions. Criteria that defined the signs for the conditional knowledge can be found in Appendix E.

The data shows that some of the participants recognised the assignment from the course, namely student 4 and 6, as can be seen from the following examples.

Example 10 – Couple 2 (during assignment)

Student 4: *This feels just like that one project 'create your own bacterium', we also read protocols there.*

Example 11 – Couple 4 (during assignment)

Student 6: *Oh, just like that you had to put those protocols together. 'First do this one, then the second one'. You know, that second assignment?*

However, while the participants did recognise the assignment and it's goals, they could not remember or reproduce the input/output-model and/or its strategies. Examples 12 through 14 show that when asked, students argue that they were not taught how to write the work plan.

Example 12 – Couple 2 (during interview)

Interviewer: *So, what you've learned in that assignment helped to do this assignment?*
Student 3: *Well, you also had to put the protocols in the right order and decide what you needed and what you didn't.*
(…)
Interviewer: *And did you learn a method during that assignment that showed how to do that easily?*
Student 4: *Well, no. At least not consciously.*
Student 3: *Not that I know of.*
Interviewer: *So, you can't remember how the assignment told you to complete it?*
Student 4: *Only 'here are some protocols, good luck'*
Interviews: *So, no tips or tricks or other sort of help?*
Student 4: *No, just the same as was given to us right now.*

Example 13 – Couple 4 (during interview)

Interviewer: *And did you learn a certain method to do that? I mean, to write that work plan?*
Student 7: *Good question. It did say things like 'this one should come after the other and this one before that one', but I can't remember in detail.*

Example 14 – Couple 3 (during interview)

Interviewer: *Was there any method you had to use in order to do [the course's] assignment?*
Student 5: *What do you mean, like, using a protocol?*
Interviewer: *You had to write a work plan during that assignment as well, so did you have to use a certain method to do that?*
Student 5: *Let's see, I don't think anything was said about how you had to write the work plan. You did get a list of protocols, but you had to figure out how to do it all by yourself.*

After these questions the participants were all shown a replica of the input/output-model used during the biotechnology assignment, accompanied by the question if they recognised the scheme from the assignment. All participants recognised the scheme. In addition, the six participants who worked in couples could explain how the model worked and how it should be used to write a work plan, as the following examples show.

Example 15 – Couple 1 (during interview)

Student 2: *It helps to put all the protocols in order, because you have to write down what goes into the protocol and what comes out. And when you do that you also know what goes into the next protocol.*

Example 16 – Couple 4 (during interview)

Student 7: *You know where to start with, what the result will be and which steps are necessary to get to the output. Then you can use the output to go on.*

Student 6: *Yes, the output is used for the next one.*

When asked about the purpose of the model, some of the students were able to explain that the input/output-model made sure that you could review your work plan easily to spot any gaps in the chain of protocols, which was one of the course's learning goals in the assignment. This becomes apparent in examples 17 and 18.

Example 17 – Couple 1 (during interview)

Student 1: *Actually, it forces you to…*

Student 2: *…Not make the mistake we made.*

Student 1: *It helps to clearly write it down. You see what goes in and what comes out. That way you really can't overlook a step in the way we did.*

Example 18 – Couple 2 (during interview)

Student 4: *You can quickly see whether the output of this protocol is the input of the next one and whether you've missed any steps.*

Interviewer: *So you could use it to verify your work plan?*

Student 3: *Yes.*

These statements show that students do understand the way the input/output-model works and what its intentions are. However, this seems to be conflicting when compared to the participants' performance, where none of the couples have reproduced the model precisely. In addition, none of the participants seemed to actively reflect on the assignment in the way they explained in the interview. No active reflection was seen on the steps that they had written down in their work plans. Therefore there seems to be a gap between the understanding of the model and actively using the learned strategy. In terms of metacognition it seems that the results show a lack of conditional knowledge in the participants' metacognition.

Conclusions

This evaluative study aimed to assess whether students who attended the first-year course of 'Biotechnology' had acquired the metacognitive knowledge necessary for experiment design, taught by the use of an assignment created by the course's coordinator and was based on the HLT by Postma (2013). Therefore, the research question that was formulated for this study was: *to what extent does a problem-solving approach with minimal scaffolding contribute to undergraduate students' metacognitive knowledge on designing experiments?*

To help answering this research question the following sub questions were formulated:

- To what extent are undergraduate students' intuitive problem-solving strategies integrated in their metacognitive procedural knowledge regarding experiment design?
- To what extent is the proposed input/output-model part of undergraduate students' metacognitive conditional knowledge?

In general it can be said that in its current form, the course's assignment, as was given in the college year of 2014, does not yet reach the goals of teaching students the metacognitive knowledge necessary for experiment design. The work plans created by the participants in this study show that students were not able to fully reproduce the strategy taught during the assignment and do not actively reflect on their performance. Therefore, the input/output-model and its strategy used for writing a work plan is not yet a part of the students' metacognitive knowledge of cognition.

Regarding the extent to which the input/output-model and the biotechnology course's assignment contributed to the students' metacognitive procedural knowledge it can be said that the intuitive problem solving strategies of problem decomposition and means-end analysis are actively used by the student, and can therefore be considered to be part of the students' procedural knowledge. However, this cannot be clearly attributed to the effects of the assignment. Problem decomposition and means-end analysis are strategies which are intuitive by nature (Dhillon, 1998). This means that these strategies may already have been a part of the students' procedural knowledge and were not learned during the biotechnology assignment.

To answer the second sub question, it is clear that students have a shortcoming in their metacognitive conditional knowledge regarding the use of the input/output-model as a strategy for experiment design.

This lack in conditional knowledge is predominantly seen in the fact that none of the students remembered the input/output-model from the assignment, but were able to recognise it and explain its features when explicitly shown.

The amount of scaffolding used in the course's assignment does not seem to be the bottleneck in teaching the input/output-model. The results showed that although less scaffolding was provided to the students, the intuitive problem-solving strategies were still used by the students. In addition, the course's assignment could be completed by all students with positive results. When teaching metacognitive conditional knowledge to the student, it is questionable to assume this can be achieved through scaffolding, since the purpose of scaffolding is meant to guide students through an assignment and not to teach the actual concepts themselves. Therefore, other means of teaching the necessary conditional knowledge need to be sought after.

In conclusion, the research question of this study can be answered by saying that the problem solving approach used in the assignment, taught using minimal scaffolding, mainly contributes to -or activates- the students' metacognitive procedural knowledge. The assignment, and its problem-solving approach, does not yet contribute to the students' metacognitive conditional knowledge. Therefore, new criteria should be defined on the guidance of the student. The focus of these criteria should be on stimulating students to learn when to use the strategy taught in the assignment in other situations. This means that the new criteria should focus on teaching metacognitive conditional knowledge, rather than procedural knowledge. A suggestion on how to do this, is by explicating the purpose and benefits of the assignment and its strategies to the student. This way it becomes clear how, when and why to use input/output-model during experiment design.

Discussion

Advice for improvement on the course's assignment

The general force behind this study was the assignment used in the biotechnology course, which in turn was based on the study by Postma (2013). The conclusions in this study show that further improvement is necessary in order for the assignment to reach its set learning goals. As was concluded in the study, the assignment should mostly be improved in terms of stimulating the students' metacognitive conditional knowledge. This is said because the results of the interviews with the participants show that while students cannot remember the model to any degree, they were able to explain the model and its purpose in detail when the model was shown. This clearly shows that the students are missing a trigger necessary to "unlock" this knowledge. Explicating the purpose and benefits of the input/output-model and it's underlying problem solving strategies may help creating this trigger for students providing them with the conditional knowledge. One way this may be accomplished is by means of "aftercare" of the assignment. By reflecting on the assignment and the students' performance it should be possible to explicate the purpose of the model to the students.

In addition, emphasising the necessity of the input/output-model when writing a work plan may also clear the students' ideas of not using the model when an experiment is deemed too straight-forward. Couple 4 mentioned during the interview that they wouldn't use the model when an experiment follows a straight line when going from a starting material to the ending material. While it seems understandable not to use the model in this situation because of the extra work it asks of the student, the downside of this is that students miss out on the possibility to easily reflect on their work plan in terms of finding gaps in the chain of the work plan.

Limitations of the study

In this study, several practical issues may have caused a limitation in its results and outcomes. First of all, apparent gaps in theoretical knowledge of the student may be attributed to the period of time in which this study was performed. Because of changes in the curriculum of the biology bachelor's study at Utrecht University the biotechnology course changed its place in the semesters of the college year. This resulted in the course taking place in the period of February-May, instead of the

period of May-July as was the case in previous years. Because the window of opportunity for data collection in this study was in the semester of May-July, the change in curriculum for the biotechnology course resulted in a 7-10 week gap between the students attending the course and participating in this study. There may have been an effect in this gap, where some of the theoretical knowledge on the course's concepts may have "sunk away" in the students' knowledge on the subject, hampering their performance in this study.

Another limitation of the study was a lack of students available to participate. As the participation in this study was voluntary and asked students to participate in their own free time only seven of the estimated 130 students who were enrolled in the biotechnology course participated in the study. This small group size limits the ability to make strong claims on the results of this study. In addition, it is expected that because of the voluntary nature of the experiment, the students who participated in the study did so on the basis of intrinsic motivation and are assumed to be the more successful students in the group, shifting their performance upwards from the average. However, some of the participants have mentioned to have failed the first exams of the course and were expected to redo this exam in early July.

The use of scaffolding

The main focus of the research was on the difference between the HLT by Postma (2013) and the HLT of the course's assignment. This was mainly because this difference was the only one found when comparing the two. Because of this, the assumption was made that if there was to be found that students' understanding of the input/output-model did not meet the course's learning goals, this mainly could be attributed to the lack of scaffolding. However, while the first statement in this assumption turned out to be true, the question should be asked whether the second statement is true as well.

As can be seen in Postma's HLT in appendix B2, the focus of the scaffolding is on teaching how the input/output-model works and less on when the model should be used in future situations. This seems contradictory when considering that the problem solving strategies that make up the input/output-model are said to be intuitive by nature. If this is the case, students should be able to use the model and its strategies by themselves, perhaps not needing so much scaffolding as was offered in Postma's HLT. In extension to this, it could mean that the lack of this extensive scaffolding in

the course's assignment may not have had a negative impact on the students of the biotechnology course.

When considering the theory behind scaffolding, as was explained earlier on, the goal of scaffolding is to guide the student during (mostly) inquiry-based learning activities, after which scaffolding is gradually removed and students are able to work independently (Sawyer, 2006; Hmelo-Silver, Golan Duncan, & Chinn, 2007). Postma (2013) divided these actions during scaffolding into three distinctive phases: Building up, fading and handing over to independence, as can be seen in appendix B2. It could be argued that dividing the scaffolds into explicit phases is not actually necessary, as scaffolding may be considered a continuous process. In combination with the fact that the problem solving strategies taught are intuitive by nature, this may have led to an overabundance of scaffolding for the students in the study by Postma (2013).

The explication of learning goals in general

The findings in this study suggest that the biotechnology assignment appears to be teaching the input/output-model and its strategies for experiment design to the students sufficiently in terms of metacognitive procedural knowledge, but not yet in terms of conditional knowledge. Because of this, the learning goals set for the assignment need to be revised, so the focus is shifted towards learning metacognitive conditional knowledge.

The findings of this study can possibly be applied to the goals of science education in general. Explicating the benefits of certain strategies or similar aspects of science curricula to students may possibly stimulate them to reach science education's goals of the student being able to perform research. Further investigation in the way these goals are explicated to students in different parts of the science curricula at university level should be done in order to confirm both these suggestions and similar arguments made by Boerwinkel (2014).

In addition, this study has created a basis for further investigation in the way metacognitive knowledge can be taught to students. It seems that there is a gap in the theoretical knowledge on metacognitive conditional knowledge, and the essential part this plays in educating the strategies and skills of which this conditional knowledge is part of. The way the goals of science education may be reached by explicating these goals more to the student may also contribute to more theoretical insights in the way metacognitive conditional knowledge can be taught to students in science education.

These insights could then be used to adapt science curricula in order to reach these goals in order to stimulate students to acquire the knowledge skills and attitude needed to perform scientific research.

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Appendix A: Dutch assignment used in the biotechnology course

Project 1: Ontwerp je eigen *Escherichia coli*

Doel van de opdracht Het in groepsverband bedenken van een *E. coli* met een toepassing en het maken van een werkplan voor de constructie van de bacterie. We maken hierbij gebruik van Biobricks. Dit zijn DNA modules die gebruikt worden in de synthetische biologie en die zo gemaakt zijn dat ze eenvoudig aan elkaar gekoppeld kunnen worden.

Praktische informatie

- De opdracht wordt uitgevoerd in de groep van de werkcolleges.
- Op vrijdag tussen 9.00 en 10.00 kunnen de groepen de uitgeprinte lijsten en de protocollen komen ophalen. Ze zijn ook te vinden op blackboard.
  Groep A1 en A2 in MINNAERT 018

  Groep A3 en B1 in MINNAERT 022

  Groep B2 en B3 in MINNAERT 023
- **Belangrijk!! Spreek vrijdag 21 februari vroeg af, want de tijd voor de opdracht is kort.**
- De opdracht mag gedaan worden op een willekeurige plaats, maar de volgende zalen zijn beschikbaar. De hele dag beschikbaar: MINNAERT 018, 022, 023, 025. Vanaf 13.15 zijn ook MINNAERT 016 en 021 beschikbaar.
- Jullie product en werkplan moeten ingevuld worden op een formulier. Dit formulier is te vinden op blackboard bij de assignments, project 1.
- Inleveren moet via blackboard, maar als dat niet lukt dan kan het per mail gestuurd worden naar *Censored*. De deadline is maandag 24 februari om 21.00.

Uitvoering

Stap 1 Iedereen bestudeert individueel de opdracht en maakt zich vertrouwd met de werking van de biobricks (zie bladzijde 3 en 4). Hiervoor is woensdagmiddag 19 februari bedoeld.

Stap 2 Ontwerpen van de bacterie. Bedenk een *E. coli* die een nieuwe eigenschap heeft gekregen en die gebruikt kan worden voor een bepaalde toepassing. Om de bacterie een nieuwe eigenschap te geven zijn de volgende onderdelen minimaal nodig.

- een plasmide om nieuwe eigenschappen te introduceren (zie lijst 1).

- een promoter – de keuze van de promoter bepaalt wanneer de eigenschap (het gen of het operon) tot expressie komt (zie lijst 2A en B) voor beschikbare promoters).
- de coding region (een gen of meerdere genen) die coderen voor een bepaalde eigenschap (zie lijst 3 voor de beschikbare eigenschappen).

De lijsten geven de beschikbare biobricks aan. Biobricks worden aangeleverd op een vector pMC1 in een *E. coli* stam (E. coli DH5α). Ze moeten dus eerst geïsoleerd worden voordat ze gebruikt kunnen worden voor het kloneren.

Extra mogelijkheden: je kunt je bacterie complexer te maken door niet één, maar twee eigenschappen in te brengen. Ook kun je een gen fuseren met de DNA sequentie van een signaal peptide, waardoor het eiwit door de bacterie wordt uitgescheiden of blijft hangen aan de buitenkant van de cel. Dit kan alleen bij bepaalde biobricks. Zie voor extra informatie lijst 3.

Stap 3 Opstellen van het werkplan. Als je bedacht hebt hoe de bacterie eruit ziet, dan kun je gaan bedenken hoe je dit voor elkaar kunt krijgen. Eerst bedenk je welke biobricks je nodig hebt en dan maak je een werkplan.

Het werkplan wordt op de volgende manier gemaakt:
Input (uitgangsmateriaal) - protocol - output (resultaat) - tijdsduur

De input is datgene wat nodig is voor het experiment. De materialen die standaard beschikbaar zijn (zie protocol) hoef je niet in het werkplan aan te geven. Soms kom je er achter dat je nog niet alles hebt en dat je nog een stap extra moet inplannen. Bij Protocol staat het protocol dat je nodig hebt voor je experiment. Bij Output wordt beschreven wat het eindproduct van het experiment is. Bij Tijd wordt aangegeven hoeveel tijd ongeveer nodig is om het experiment uit te voeren. Hieronder staat een voorbeeld van de manier waarop het moet worden aangegeven.

Stap	Input	Protocol	Output	Tijd
1	- E. coli DH5α met plasmide pMC1 - Kweekflesje met medium met ampicilline	Protocol 5 Kweken van bacteriën	Volgroeide cultuur E. coli met plasmide pMC1	24 uur
2	- Cultuur E. coli met plasmide pMC1	Protocol 3 Isoleren van plasmiden	Geïsoleerde plasmiden	3 uur

Beoordeling

De opdracht wordt beoordeeld op drie criteria: originaliteit, toepasbaarheid en kwaliteit werkplan.

De groep die de opdracht het beste uitvoert wint een prijs.

De werking van het biobrick systeem

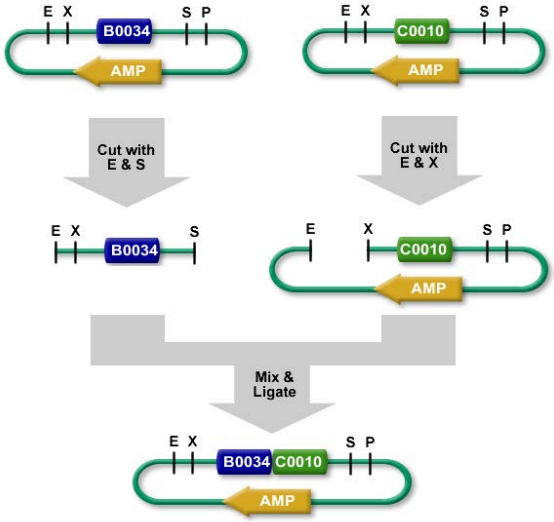
Biobricks zijn DNA modules die makkelijk met elkaar gecombineerd kunnen worden. Ze hebben altijd dezelfde restrictiesites aan beide kanten liggen. Dat zijn aan de ene kant EcoRI en XbaI en aan de andere kant SpeI en PstI. De modules zijn zo gemaakt dat deze restrictiesites niet aanwezig zijn in de biobricks zelf.
Hieronder zie je de herkenningssites voor deze enzymen. De ▼ geeft de positie van de knipplaats weer.

EcoRI G▼AATTC
XbaI T▼CTAGA
SpeI A▼CTAGT
PstI CTGCA▼G

Fusie XbaI/SpeI T▼CTAGT (geen genetisch palindroom meer).

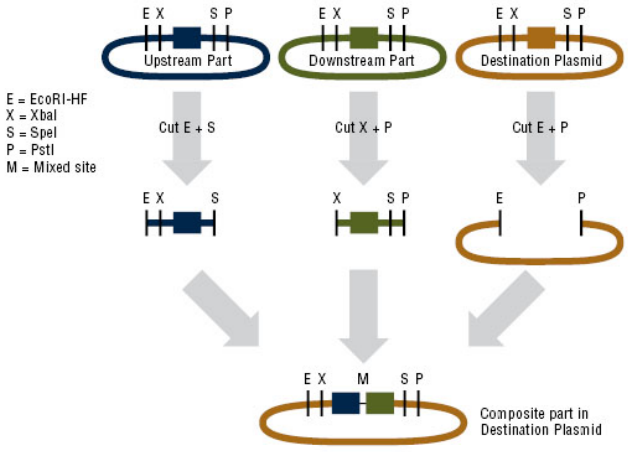
Het principe achter de biobricks is dat de restrictie-enzymen XbaI en SpeI niet identiek zijn, maar wel compatibel omdat ze dezelfde sticky uiteindes hebben. Je kunt ze dus wel aan elkaar plakken, maar daarna zijn beide sites niet meer intact

(hetzelfde principe hebben we gezien in assignment 2, opdracht 1). Je zorgt er steeds voor dat er geen intacte restrictiesites tussen de biobricks zitten, terwijl die er buiten wel intact blijven en hetzelfde blijven. Hierdoor kun je biobricks blijven introduceren in een construct.



Figuur 1 Kloneren van biobrick B0034 voor biobrick C0010. B0034 wordt eruit geknipt geknipt met EcoRI en SpeI. De vector met biobrick C0010 wordt opengeknipt met EcoRI en XbaI. Na ligatie krijg je een fusiesite tussen SpeI/XbaI die niet meer intact is. De EcoRI site blijft wel intact.

Het is ook mogelijk om biobrick B0034 achter C0010 kloneren, alleen knip je B0034 er dan uit met XbaI en PstI en knip je de vector met C0010 open met SpeI en PstI. Ook is het mogelijk om twee biobricks tegelijk in een lege vector te zetten. Zie figuur hieronder.



Appendix B: HLT described in retrospect for biotechnology assignment and comparisons with Postma (2013)

In this appendix the full HLT of the course's assignment and a comparison with the HLT used in the study by Postma (2013) can be found. The HLT by Postma, in appendix B2 is marked in bold where the course's assignment overlaps the HLT's content.

B1: Full HLT as described for biotechnology course's assignment

Phase of scaffolding	Problem Solving element	Learning activity	Scaffolding		Student activity	Hypothesised learning result
			Verbal	Visual		
1. Building up the scaffold	Introducing the operators in the problem space.	**LA1** Preparation The topic and assignment are presented through the text of the assignment. Students will familiarise themselves with the general concepts and goals.	Introductory text about the research topic and method, including step-by-step guidelines to complete the assignment.	Images and schematics of the 'Biobrick'-system. Visual representation of the input/output-model	Student reads the contents of the assignment.	Student understands the topic (Genetically modifying an *E. coli* bacterium) and recalls the concepts 'Biobricks', 'restriction sites', 'cloning' and relating concepts as was covered during lectures.
No scaffolding	None	**LA2** Filling in context Students are asked to design an *E. coli* with an enhanced promoter and gene/operon, giving it a new (commercially useful) ability.	None	None	Student picks a plasmid, promoter and gene(s) fom the list and describes the reason of choice on the answer sheet provided.	Student gains insight in the way new research is formulated. Student can provide solid arguments to justify a research.

		Different promoters and genes/operons can be chosen from extensive list. A suitable plasmid needs to be chosen as well				
3. Handing over to indepen-dence	Applying problem-decomposition and means-end analysis.	LA3 Designing the experiment Students are asked to write a work plan using the input/output-model according to the scheme presented in the guidelines. The different steps needed to design the experiment must be found in several protocols provided, each containing a biotechnological technique.	Step-by-step guidelines, including an explanation of the input/output-scheme shown. Protocols containing the biotechnological techniques to write the work plan. Teacher available for questions.	Scheme of the input/output-model, shown in the assignment's guidelines and on the provided answer sheet.	Student uses description of the chosen plasmid, biobricks etc. and searches for the correct protocols, guided by the framework of the input/output-model: Describe input, find the suiting protocol, describe output, find next protocol etc.	Student understands that a research method consists of several techniques and that one technique provides the starting point for the next. Student will reflect on work plan to see gaps in research method and is able to correct them.

B2: Comparison with Postma (2013)

Sections that are highlighted in bold are sections where overlap is found between the course's HLT and Postma's HLT.

	Problem solving element	Learning activity	Scaffolding		Student activity	Hypothesized learning result
			Verbal	Visual		
Experiment 1: Building up the scaffold	Not applicable.	LA1: General introduction in *F. candida* reseach and cDNA libraries **The research topic and methods are presented.** Students' prior knowledge about the most important concepts of the research topic and method are called upon. They are asked to describe what cDNA libraries constitute and why this is a relevant experimental method for the *F. candida* research topic.	**Introductional text about the research topic and method**	Not applicable	Student answers question 1 and 2 in the assignment	Students understand what the *F. candida* research encompasses in terms of goal and the experimental method to be used.
	Not applicable.	LA2: General introduction in *F. candida* experiments The required experiments are presented. Students are asked to describe what the three experiments yield and why these data are needed for the *F. candida* research goal.	Introduction text about the experiments to be conducted.	Not applicable	Student answers question 3 and 4 in the assignment	Students understand why the 3 presented experiments (constructing cDNA library, screening and cloning in expression vector) are needed to generate the desired type of data.
	Creating problem space by defining starting initial	LA3: Filling in the problem space by describing starting material and end product of the experiments in the *F. candida* research	**Instructional text about the stepwise procedure between defined**	Not applicable	Student answers question 5 and 6 in the assignment	**Students learn to describe the experiments in terms of starting material and**

state and goals state.	Students are asked to describe the starting material and desired end product of the three experiments in the *F. candida* research	**starting material and desired end product of an experiment.**			**desired end product as a first step in designing an experiment.**
Introducing the operators in the problem space.	LA 4: Introducing the techniques and technical operations of experiment 1. Students are asked to describe the role of every step in the experimental work plan by describing the output of every step and the relevance of that output for generating the desired end product.	**Instructional text about the input/output dependent sequence of steps in an experiment.** The steps needed for experiment 1 are given.	Starting material, end product and the sequence of intermediate steps of experiment 1 that transcend the problem space are modelled in a scheme (figure 1)	Students answer question 7 in the assignment	**Students are acquainted with the stepwise procedure** of experiment 1 **in terms of starting material, end product and intermediate steps (=outputs and according techniques).**
Using the operators to transcend the problem space.	LA5 Introducing the input/output dependent sequence of steps in experiment 1 Students are asked to analyse the chain of input and output in the experimental work plan by explicating the	Instructional text about the technical throughput of steps in an experiment	Figure 1 could be used as a reference.	Students answer question 8 in the assignment	**Students gain understanding of the input/output dependent chain of steps in the experiment.**

		technical throughput of every step and connecting this with the input of the following step in experiment 1.				
	Using problem decomposition and means-end analysis strategies to analyse the solution.	LA6 Reflection on the sequence of steps in the experimental work plan of experiment 1. Students are asked to explain why the steps mRNA purification and molecular cloning need control experiments and with what techniques these control experiments can be performed. In addition they are asked to reason what steps can or must be repeated when a control experiment gives a negative result.		Figure 1 could be used as a reference	Students answer question 9 – 11 in the assignment	Students gain insight that the stepwise procedure of an experiment must be supplemented with checkpoint experiments and that these checkpoints influence the sequence of activities of an experiment
Experiment 2: Fading the scaffold	Creating problem space by defining initial state and goals state.	LA7 Creating a problem space by describing starting material and end product of experiment 2 in the F.candida research Students are asked to describe the relevance of experiment 2 within the F.candida research context and to define the starting material and desired end product of experiment 2.	None	None	Students answer question 14 - 16 in the assignment	Students recall what experiment 2 encompasses in terms of starting material and desired end product and the relevance of experiment 2 in the context of the *F.candida* research. Students use starting material and end product to construct a problem space.

Applying problem decomposition and means-end analysis to find operators assessing their application and transcending the problem space.	LA8 Designing experiment 2 **Students are asked to design experiment 2 by building on the initial format that has been given to them. Students are asked describe al steps needed that will allow traversal for starting material to desired end-product.**	To get students started with their problem solving process the first step in the experiment is given and students receive a hint that focuses them to match the output of the first step in the experiment (current state) with the desired end product (goal state) to find the intermediate product needed in the experiment.	The starting material and first step are modeled in the same schematic diagram used as a (visual) scaffold in LA1-LA6.	Students answer question 17 in the assignment	**Students can break the problem into a preliminary set of steps needed for experiment 2 by reasoning what intermediate products are needed and calling upon prior knowledge for seeking the according techniques/technical procedures. Students can match the input and output of the preliminary set of steps in the experiment to detect and solve gaps.**

	Problem decomposition and means-end analysis to detect and solve gaps.	LA9: Reflection on input/output sequence of steps in the experimental work plan of experiment 2. Students are asked to explain why the step molecular cloning needs a sequencing control experiment.	None	None	Students answer question 18 and 19 in the assignment	Students are able to critically reflect on the role and sequence of steps in the experimental workplan of experiment 2 they designed and can identify new sub problems to be solved.
Experiment 3: Handing over to independence	Creating a problem space. Applying problem decomposition and means-end analysis to find operators, assessing their application and transcending the problem space.	LA10 Designing experiment 3 Students are asked to solve the problem by finding some sequence of steps (problem solving operators) that will allow input/output dependent traversal in the problem space between the starting material and desired end product (goal state).	The first author provides information when lack of or inability to call upon relevant conceptual and/or procedural knowledge hinders students' design process. In addition, when needed the first author helps students to structure their thoughts.	None	Students answer question 20 in the assignment.	Students recall what experiment 3 encompasses in terms of starting material and desired end product and use these end-point to start the design process. **Students can break the problem into a preliminary set of steps needed for experiment 2 by reasoning what intermediate products are needed and calling upon prior knowledge for**

					seeking the according techniques/technical procedures. **Students can match the input and output of the preliminary set of steps in the experiment to detect and solve gaps**
	Problem decomposition and means-end analysis to detect and solve gaps.	LA11 Reflection on the input/output sequence of steps of the experimental work plan of experiment 3. Students are asked to describe what steps in the experimental work plan need what type of control experiments by critically analyzing the chain of input and output.	None	None	Students answer question 21 and 22 in the assignment	Students are able to critically reflect on the role and sequence of steps in experiment 3, they can describe what steps need control experiments and while analysing they can detect new sub problems to be solved.

Appendix C: Dutch evaluative assignment designed for this study

Assignment Biotechnologie – Genen isoleren in bodemdiertjes

Introductie

Het insectachtige bodemdiertje *Folsomia candida* (springstaartje) behoort tot de klasse van springstaarten. Springstaarten kenmerken zich in het algemeen door monddelen die zich in een buidel in de kop bevinden. Daarnaast hebben vrijwel alle soorten binnen de klasse een gevorkte staart. Springstaarten leven vooral in de bovenste laag van de bodem, waar ze schimmels en rottende plantendelen eten. Ze zijn dan ook betrokken bij de vorming van compost.

Figuur 1: Foto van Folsomia candida.

Onlangs is in *F. candida* ontdekt dat deze soort de mogelijkheid bezit een antibioticum aan te maken. Organismen van de soort bezitten een gen dat leidt tot de productie van het enzym isopenicilline-N-synthase. Het enzym is een belangrijk onderdeel bij het maken van het antibioticum. Het verantwoordelijke gen komt in het darmweefsel tot expressie. Wetenschappers zijn geïnteresseerd in het enzym omdat het bruikbaar is bij het produceren van antibiotica. Daarom is besloten om het gen verantwoordelijk voor de productie van isopenicilline-N-synthase op te sporen en tot expressie te brengen in *Escherichia coli* zodat het enzym eenvoudig te oogsten is.

Om dit te doen is besloten om van darmweefsel van *F. candida* een cDNA bank te maken, zodat het verantwoordelijke gen gevonden kan worden in een screening en tot expressie kan worden gebracht in een klonerings-vector.

Opdracht

In deze opdracht ga je een werkplan schrijven voor het eerste experiment van het onderzoek: het maken van een cDNA bank. Het doel van het werkplan is om een methode te schrijven die bruikbaar is om de cDNA bank te maken. Om dit te doen heb je protocollen tot je beschikking die de benodigde technieken stap voor stap beschrijven. Door de juiste protocollen te kiezen en deze in de juiste volgorde te zetten kan je de methode beschrijven. Daarnaast heb je het handboek ‘Introduction to Biotechnology’ tot je beschikking om de uitleg van begrippen op te zoeken.

Het startmateriaal van je experiment is darmweefsel dat is geïsoleerd uit *F. candida.* Beschrijf op een duidelijke manier de stappen die nodig zijn om het experiment uit te voeren en leg bij elke stap uit waarom deze belangrijk is. Houdt er rekening mee dat niet alle protocollen nodig zijn om het experiment te beschrijven.

Veel succes!

Antwoordblad (tekeningen of schema's op de achterzijde)

Protocol 1 – cDNA synthese

- Maak sample mRNA klaar door 10µg in microcentrifugebuis te brengen met een concentratie van 1µg/µL.
- Verhit het mRNA in afgesloten microcentrifugebuis bij 65°C gedurende 5 minuten.
- Voeg in respectievelijke volgorde de volgende stoffen toe in een lege buis:
    - 20µL 5mM dNTPs (500µM totaal)
    - 40µL 5x RT buffer
    - 10 µL 200mM DTT
    - 20µL 0.5mg/ml OligodT
    - 60µL H_2O
    - 10µL (10 U) RNasin
- Mix door te vortexen, centrifugeer kort in microcentrifuge en voeg mengsel toe aan mRNA oplossing. Voeg 20µL (200U) AMV reverse transcriptase toe voor een uiteindelijke concentratie van 1000U/mL in 200µL. Mix zoals eerder beschreven en scheid 10µL in een aparte buis die 1µL [α-^{32}P]dCTP bevat. Incubeer 5 min bij kamertemperatuur, daarna 1.5 uur bij 42°C.
- Voeg 1µL 0.5M EDTA, pH 8.0 aan de radioactieve reactie en bevries bij -20°C. Dit is een middel om later de hoeveelheid geproduceerde cDNA te bepalen.
- Voeg 4µL 0,5M EDTA, pH 8.0 en 200µL gebufferde phenol toe aan de hoofdreactie. Goed vortexen en microcentrifugeren op kamertemperatuur gedurende 1 minuut. Verplaats de waterlaag naar een nieuwe buis. Bewaar de oude buis met phenollaag ook.
- Voeg 100µL TE buffer, pH 7.5 toe aan de phenollaag, vortex en centrifugeer zoals in de vorige stap. Verwijder de waterlaat en voeg het toe aan de eerdere waterlaag. De phenollaag mag nu opgeruimd worden.
- Voeg 1mL diethyl ether toe, vortex en centrifiguur zoals eerder aangegeven. Verwijder de bovenste (ether)laag met een glazen pipet en herhaal met nogmaals 1mL ether.
- Voeg 125µL 7.5M ammonium acetaat en 950µL 95% ethanol toe. Plaats in droogijs/ethanol bad voor 15 minuten. Verwarm daarna tot 4°C en centrifugeer op hoogste snelheid bij 4°C gedurende 10 minuten. Een geel-witte pellet is zichtbaar
- Verwijder supernatant. Vul buis met ijskoud 70% ethanol, centrifugeer op volle snelheid voor 3 minuten bij 4°C. verwijder supernatant en droog de buis in een vacuümdesciccator.
- Ontdooi de buis met het radioactieve aliquot en spot het sample op een nitrocellulose membraanfilter.
- Was het membraan met ijskoud 10% TCA en stel de radioactiviteit vast op het filter met een fluor- en scintillatieteller. Gebruik de specifieke activiteit van het label in de reactie, de hoeveelheid gebruikte mRNA, de resultaten van de teller en de efficiëntie van de bèta-teller om de hoeveelheid cDNA die gesynthetiseerd is te bepalen.

Protocol 2 – DNA isolatie

- Bevries weefsel met behulp van vloeibare stikstof waardoor het verpoederd. Maar het weefsel zo klein mogelijk in een epje.
- Voeg 500 µL TES (100mM Tris, pH 8.0, 10mM EDTA, 2%SDS) toe
- Voeg 50-100 µg proteinase K toe van een bekende standaardoplossing, incubeer voor 30-60 minuten bij 60°C en mix elke 15 minuten.
- Voeg 140 µL 5M NaCl toe.
- Voeg 65 µL 10% CTAB toe. Incubeer 10 minuten bij 65°C
- Voeg een gelijk volume aan SEVAG toe (ongeveer 700 µL). mix voorzichtig (niet met vortex) en incubeer 30 minuten bij 0°C
- Centrifugeer met volle snelheid bij 4°C gedurende drie minuten. Pipetteer het supernatant over in een 1.5mL epje en voeg 225 µL 5M NH_4Ac toe, mix voorzichtig en incubeer op ijs voor 30 minuten.
- Centrifugeer bij volle snelheid en 4°C gedurende drie minuten. Pipetteer het supernatant over in een nieuwe 1.5mL ep en voeg 0.55x het volume aan isopropanol toe (ongeveer 510µL) om het DNA te precipiteren. Centrifugeer gelijk voor 5 minuten op hoogste snelheid.
- Wanneer er geen pellet zichtbaar is dient het sample 15 minuten op ijs te incuberen voor er gecentrifugeerd wordt.
- Verwijder het supernatant en was het pellet tweemaal met ijskoud 70% ethanol. Droog de pellet aan de lucht gedurende 15 minuten bij kamertemperatuur.
- Los de DNA op in 50 µL TE en bewaar indien nodig bij -80°C gedurende maximaal 3-4 weken.

Protocol 3 – RNA Isolatie

- Weefsel dient bij aanvang van de isolatie gekoeld en bewaard te worden met vloeibare stikstof bij -80°C.
- Voeg 1mL denaturatievloeistof toe per 100mg weefsel. Hak weefsel fijn met steriele scalpels of scharen en homogeniseer met behulp van een Glas-Teflon homogeniseerder. Bevroren weefsels mogen niet ontdooien en dient verpoederd te worden met behulp van vloeibare stikstof voordat de denaturatievloeistof wordt toegevoegd. Zorg ervoor dat de weefsels niet langer dan 30 minuten in aanraking komen met de denaturatievloeistof.
- Verplaats het weefsel naar een 4mL polypropylene buis.
- Voeg per 1mL lysaat het volgende toe in deze volgorde: 0,1mL 2M natriumacetaat, pH 4.0, en schud grondig; 1mL gehydrateerd phenol, schud grondig; 0,2mL chloroform/isoamyl alcohol (49:1), en schud stevig met de hand.
- Koel sample op ijs gedurende 15 minuten.
- Centrifugeer 20min bij 10.000G bij 4°C
- Pipetteer waterlaag van het supernatant, dat het meeste RNA bevat, voorzichtig over in een schone buis.
- Voeg 1mL isopropanol toe aan de waterlaag om het RNA te laten bezinken.
- Incubeer het sample minimaal 1 uur bij -20°C.
- Centrifugeer sample voor 20 minuten bij 10.000G en 4°C. Verwijder het supernatant. Het neergeslagen RNA is te zien als een pellet in de buis.
- Los het pellet op in 0.3mL denaturatievloeistof.
- Verplaats de oplossing naar een 1.5mL microcentrifugebuis
- Voeg 0.3mL isopropanol toe.
- Incubeer minimaal 30 min. Bij -20°C
- Centrifugeer voor 10 minuten bij 10.000G en 4°C. Verwijder het supernatant.
- Resuspendeer het RNA pellet in 0,5-1mL 75% ethanol en vortex voor een aantal seconden totdat de RNA is gesuspendeerd.
- Incubeer voor 10-15 minuten bij kamertemperatuur.
- Centrifugeer 5 minuten bij 10.000G en 4°C en verwijder het supernatant.
- Laat RNA aan de lucht drogen voor 5-10 minuten.
- Los het RNA op in 100-200µL DEPC-behandeld water of 0.5% SDS. Incubeer voor 10-15 minuten bij 60°C om verzekerd te zijn van oplossing

Protocol 4 – Kloneren van cDNA in een vector

- Knip 5µg van de vector met het restrictie-enzym *Eco*RI. Voeg 1/10^{e} van het volume aan 3M natrium acetaat toe en voeg 2.5x het totaalvolume aan 100% ethanol toe.
- Precipiteer de vector bij -20°C. Centrifugeer in een microcentrifuge en verwijder het supernatant. Was pellet met 70% ethanol.
- Centrifugeer met een microcentrifuge en verwijder het supernatant en laat 10-15 minuten drogen in een vaccumeerpomp.
- Resuspendeer de vector die geknipt is met *Eco*RI in 50 µL T4 DNA polymerase reactiemix zonder dTTP en incubeer gedurende 1 uur bij 16°C.
- Verwarm de reactie tot 65°C gedurende 15 minuten om het enzym te stoppen.
- Zuiver de plasmide op met behulp van een gel-purificatie om sporen van ongeknipte vector-DNA te verwijderen.
- Scheidt 50 µL van het eerder verkregen cDNA van eventuele primers en kleine stukken cDNA indien nodig met behulp van een Chromaspin-100 spin kolom.
- Verdun de cDNA tot 1mL in TE en meet de concentratie van het cDNA met behulp van een A_{260} UV spectrofotometer.
- Precipiteer de cDNA met 1mL 95% ethanol. Centrifugeer met een microcentrifuge en verwijder het supernatant. Was met 70% ethanol, centrifugeer en verwijder het supernatant. Laat drogen met een vaccumeerpomp.
- Resuspendeer in 50 µL T4DNA polymerase reactie mix zonder dATP en incubeer gedurende 1 uur bij 16°C en daarna bij 75°C gedurende 10 minuten.
- Voeg 1 µL (100ng) *Eco*RI-geknipte vector toe aan 400ng cDNA. Verdun met 10 µL TE. Voeg 10 µL ligatiemix toe en incubeer overnacht bij 16°C.
- Transformeer de vectoren naar een competente competente *E. coli*-stam om de cDNA bank te maken.
- Om te toetsen welk percentage van transformatie heeft plaatsgevonden wordt een blauw/wit-selectie gehanteerd. Indien gewenst kan de gemiddelde cDNA grootte gemeten worden door een PCR reactie uit te voeren met een L-primer

Protocol 5 – Het primen van cDNA

- Resuspendeer de pellet van de andere buis in 284µL water en voeg in deze volgorde de volgende stoffen toe:
    - 4µL 5mM dNTPs
    - 80µL 5x second-stand buffer I
    - 12µL 5mM β-NAD+
- 2µL 10µCi/µL [α^{32}P]dCTP
- mix door te vortexen en voeg de volgende stoffen toe:
    - 4µL RNase H
    - 4µL *E. coli* DNA ligase
    - 10µL *E.coli* DNA polymerase
- Mix door te vortexen en incubeer overnacht bij 14°C
- Na de second-strand synthese wordt 4µL van de reactie naar een nieuwe buis gepipetteerd en bevroren bij -20°C zodat later de incorporatie van de radioactieve labels bepaald kan worden met een nitrocellulose membraanfilter zoals eerder beschreven is.
- Extraheer de second-strand synthese reactie met 400µL gebufferde phenol en extraheer de phenolfase terug met 200µL TE buffer, pH 7.5 zoals eerder aangegeven.
- Voeg de twee waterfases samen en extraheer tweemaal met 900µL ether zoals eerder aangegeven is. Er is ongeveer 600µL waterfase over.
- Verdeel de waterfase gelijkwaardig over twee buizen, voeg ammonium acetaat en ethanol toe zoals eerder beschreven is en precipiteer de cDNA
- Rond de synthese van cDNA af door de uiteindes van het cDNA blunt te maken door de pellets te resuspenderen in 42µL water. Voeg de volgende stoffen in deze volgorde toe:
    - 5µL 5mM dNTPS
    - 16µL 5x TA buffer
    - 1µL 5mM β-NAD+
- Vortex en microcentrifugeer, voeg vervolgens de volgende stoffen toe:
    - 4µL van 2µL/mL RNAse A (100ng/ml)
    - 4µL RNAase H
    - 4µL *E. coli* DNA ligase
    - 4µL T4 DNA polymerase
- Mix nogmaals en incubeer voor 45 minuten bij 37°C
- Voeg 120µL TE buffer toe, pH 7.5, en 1µL 10mg/ml tRNA. Extraheer met 200µL gebufferde phenol en extraheer de phenolfase met 100µL TE buffer zoals eerder beschreven.
- Voeg de twee waterfases toe en extraheer met 1ml ether zoals eerder beschreven.
- Precipiteer het cDNA met ethanol zoals eerder beschreven waardoor een kloneerbaar cDNA ontstaat.

Protocol 6 – mRNA zuivering

- Voeg 200-300 µL van het totaal geïsoleerde RNA toe aan 15 mL FastTrack Lysebuffer en schud voorzichtig.
- Verwarm tot 65°C gedurende 5 minuten en koel terug op ijs gedurende 1 minuut.
- Voeg 950µL 5M NaCl toe en zwenk voorzichtig.
- Voeg een gelijk deel Oligo dT toe, incubeer 2 minuten bij kamertemperatuur en zwenk daarna om Oligo dT volledig op te lossen.
- Incubeer in zwenkmachine gedurende 3-4 uur bij kamertemperatuur of overnacht.
- Centrifugeer bij 3000G gedurende 5 minuten
- Verwijder voorzichtig het supernatant en resuspendeer het pellet in 20mL bindingsbuffer
- Centrifugeer bij 3000G gedurende 5 minuten
- Verwijder supernatant, resuspendeer in 10mL bindingsbuffer en centrifugeer nogmaals
- Verwijder supernatant en was tweemaal met 10mL natriumarme buffer. Centrifugeer bij 3000G gedurende 5 minuten.
- Voeg resterende Oligo dT toe aan een 2mL epje.
- Was de Oligo dT eenmaal met 0,5 mL natriumarme buffer.
- Verdun de mRNA in een schoon 2mL epje met behulp van 250µL FastTrack verdunningsbuffer die voorverwarmd is tot 65°C.
- Voeg oplossingen aan elkaar toe. Totaalvolume is nu 500µL.
- Precipiteer het mRNA door 75µL 2M natriumacetaat toe te voegen. Voeg 1.25 mL 200proofETOH toe en plaats sample op -80°C voor 15 minuten of totdat het sample volledig bevroren is.
- Ontdooi en precipiteer mRNA door te centrifugeren. 3000G bij 4°C gedurende 20-30 minuten.
- Verwijder het supernatant en laat het pellet 15-25 minuten drogen bij kamertemperatuur.
- Resuspendeer het mRNA in 10-20µL DEPC-DH20 en gebruik naar wens 1µL voor een A260-meting om concentratie mRNA te bepalen.

Voorbeeld antwoordmodel

Stap	Input	Protocol	Output	Reden
1	Darmweefsel van *F. candida*	Protocol 3 – RNA isolatie	Alle RNA van het darmweefsel van *F. candida*	Het RNA van het weefsel moet geïsoleerd worden om het mRNA te kunnen verkrijgen.
2	RNA van darmweefsel van *F. candida*	Protocol 6 – mRNA zuivering	mRNA van darmweefsel *F. candida*	Het mRNA, dat gescheiden moet worden van RNA, is een bewijs dat er expressie is van het enzym en is daardoor een goede basis voor een cDNA bank.
3	mRNA uit darmweefsel *F. candida*	Protocol 1 – cDNA synthese	cDNA van mRNA darmweefsel	De cDNA is nodig om de cDNA bank te maken
4	cDNA	Protocol 5 - Het primen van cDNA	cDNA met blunt-ends	Het cDNA wordt voorzien van blunt-ends zodat het geplakt kan worden aan de *Eco*RI restrictiesite van de vector waarin gekloneerd gaat worden.
5	cDNA met blunt-ends	Protocol 4 – Kloneren van cDNA in een vector	*E. coli* stam met vector die cDNA bevat	De cDNA moet in een vector geplakt worden om naar een bacterie getransformeerd te worden. Waneer de vector naar een bacterie is getransformeerd kan een cDNA bank gemaakt worden uit de bacterie.

Hulpkaart bij opdracht

Het onderstaande schema kan gebruikt worden bij het schrijven van een werkplan. Door het schema te gebruiken is op een overzichtelijke manier te zien welke stappen genomen moeten worden om tot een volledig werkplan te komen. Het schema kan op de volgende manier ingevuld worden:

- Input: Hier schrijf je de materialen waarmee je een techniek of protocol begint.
- Protocol: Hier schrijf je op welk protocol je gaat gebruiken om de materialen te manipuleren
- Output: Hier schrijf je op wat de techniek oplevert. De output van de techniek is het startpunt, dus de input, van de volgende techniek.

Stap	Input	Protocol	Output	Reden van gebruik van dit protocol
1	Darmweefsel van *F. candida*			
2				
3				

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Appendix D: Backbone used in evaluative interview

Mening over de opdracht

- Wat vond je van de opdracht?
- Was de opdracht erg moeilijk? Waarom?
- Was de opdracht erg makkelijk? Waarom?
- Vond je de inhoud van de opdracht passen bij de cursus biotechnologie?
- Waren er dingen die onduidelijk waren over de opdracht?
- Had je moeite met de theorie die in de opdracht naar voren kwam? Heeft je dat belemmerd om de opdracht te maken?

Over de resultaten van de opdracht

- Het is niet gelukt om de opdracht volledig te maken. Waardoor denk je dat dat komt?
- Wist je hoe je de opdracht aan moest pakken?
- Had je het gevoel dat je de opdracht op de juiste manier aanpakte?
- Had je het idee dat er een bepaalde manier was om deze opdracht op te lossen?
- Je methode is niet helemaal kloppend. Waardoor denk je dat dat komt?
- Had je dit wellicht kunnen controleren? Hoe dan?

- **indien model niet gebruikt is dit laten zien**
    - Herken je dit schema?
    - Waar heb je dit schema eerder gezien?
    - Weet je hoe dit schema werkt?
    - Zou je dit schema gebruiken in de opdracht?
    - Hoe zou je dit schema kunnen gebruiken?
    - Wat denk je dat het doel is van het schema?
    - Denk je dat dit schema bruikbaar is voor zo'n opdracht?
    - Denk je dat zo'n schema te gebruiken is voor andere situaties? Kan je voorbeelden geven?

- **indien er een andere strategie is gebruikt**
    - Wat is de reden dat je de opdracht op deze manier hebt gemaakt?
    - Kan je uitleggen hoe de methode werkt die je hebt gebruikt?
    - Daarna schema laten zien en vragen stellen.

- Indien alles juist is
    - Waar heb je deze methode vandaan gehaald?
    - Kan je uitleggen wat je met dit schema precies kan?
    - Wat zou het doel zijn van dit schema?
    - Zou je uit kunnen leggen waar het voor gebruikt kan worden in wetenschappelijk onderzoek?
    - Zou je dit schema ook voor andere opdrachten gebruiken? Waarom?

Appendix E: Scheme of labels used for coding transcripts

The following table shows the labels used to code the transcripts of the captured discussions during the evaluative assignment and interview. The criteria that were assessed during the evaluation phase have activities that are part of that particular criterion. Each activity was given a label used during coding.

Criterion	**Student Activity**	**Code/label**
Understanding of concepts	Students question the definition of a cDNA (bank)	CON.01a
	Students describe an incomplete/incorrect definition or use for a cDNA (bank)	CON.01b
	Students describe the correct definition of a cDNA (bank)	CON.01c
	Students identify the correct use for a cDNA (bank)	CON.01d
	Student(s) consult textbook in order to look up a term or concept	CON.03
	Student(s) consult textbook in order to look up a procedure/method	CON.04
	Student states incorrect fact/term/definition	CON.WR
	Student states correct concept/fact/term/definition	CON.RI
	Student is unsure about a concept/fact/term/definition	CON.UN
Use of Problem decomposition (Part of metacognitive procedural knowledge)	Students identify the protocols as smaller sections of a complete work plan	PDC.01

Use of means-end analysis (part of metacognitive procedural knowledge)	Students note step-wise procedure of experiment	MEA.01
	Students try to chain protocols by their respective input/output	MEA.02
	Students reflect on their work in order to find gaps in their chain of protocols	MEA.03
	Students correct for gaps in their work after reflecting on their results	MEA.04
Signs of metacognitive conditional knowledge	Students recognize assignment from the biotechnology course	MCK.01
	Student recognizes strategy used in biotechnology assignment	MCK.02a
	Student recalls strategy used in the biotechnology assignment	MCK.02b
	Student partly reproduces the input/output-model	MCK.03
	Student reproduces a correct but differing variety of the input/output-model	MCK.04
	Student used exact model as was proposed in the biotechnology assignment	MCK.05
Understanding of input/output-model's intentions	Student explains how the step-wise procedure of the input-output model works	IOM.01
	Student explains how the model is used to reflect on the steps in the procedure	IOM.02
	Student links the input/output-model to the way a research method is created in scientific research.	IOM.03