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Marja Talikka

**RECOGNIZING REQUIRED CHANGES TO
HIGHER EDUCATION ENGINEERING PROGRAMS'
INFORMATION LITERACY EDUCATION AS
CONSEQUENCE OF RESEARCH PROBLEMS
BECOMING MORE COMPLEX**

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Thesis for the degree of Doctor of Science (Technology) to be presented with due permission for public examination and criticism in the Auditorium 2310 at Lappeenranta University of Technology, Lappeenranta, Finland on the 24th of August, 2018, at noon.

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Abstract

Marja Talikka

Recognizing required changes to higher education engineering programs' information literacy education as a consequence of research problems becoming more complex

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Challenges in the Earth's sustainable development set requirements to modern engineering education. Engineers face complex problems, which need to be solved to keep the planet viable for future generations. This study was conducted to find out what kind of changes should be made to the practice and to the content of information literacy (IL) education in order to provide students attending higher education engineering programs with knowledge and skills they need in solving the engineering problems of the modern world. While IL teaching resources at Lappeenranta Academic Library are limited, IL education at the Lappeenranta University of Technology (LUT) is carried out either online or as brief IL education sessions, which are integrated in substance education. This study focuses on the effects of brief integrated IL education on students' information literacy and their ability to recognize the complex issues of their research problems.

This study reports how brief IL education can be developed to fulfill the information literacy needs of modern engineering research and design successfully. Brief IL education sessions, which based on results of observations about IL skills and knowledge that student lack, were integrated in mechanical engineering seminar courses which aimed at finding the most sustainable materials for given application and in a basic course of environmental technology. The objective was to find out if students' research accomplishments and research understanding would benefit from the brief IL sessions.

The research based on transcribed student answers to surveys and interviews, which were analyzed according to the Miles & Huberman method and teachers' evaluations of learning outcomes. Classifications for categorizing student answers were created to study changes in their information searching and research skills. The qualitative results were quantified according to the classifications. Changes in searching skills were studied by using the Webropol survey tool before and after IL education to find out about changes in the use of search words and information sources. Mechanical engineering seminar students' research problem formulations analyses based on a four-step classification which was created for this research by applying Ackoff's knowledge hierarchy (Ackoff 1989) and Fava's sustainability maturity curve (Fava 2014, Burgess 2014). The development of students' information search questions was studied by using a six-point classification tool which is based on the model of the stages of information searching

presented by Kuhlthau (1993) and further developed by Vakkari (2000) and on the six cognitive process categories of Bloom's taxonomy (Anderson, Krathwohl 2001). Both analyses, the research problem formulation and information search question development, were done from the perspective of sustainability issues appearing in students' questionnaire answers.

Based on the results, brief integrated IL education appears to advance students' searching skills, their ability to understand and outline their research problem, and the way they formulate their information search questions to find literature for solving the interdisciplinary research problem at hand. Integrating the presented kind of brief IL education sessions into substance education enhances students' understanding of the complexity of their research problems and the procedure to find suitable information to solve those problems. In addition to developing their ability to do research, they also learn to observe their problems from a wider perspective and e.g. take into account sustainability challenges of their topics. From the engineering program's viewpoint, the fact that students engage in interdisciplinary issues of their research problem as a result of integrated IL education is an advantage and saves faculty teaching resources when experts of all linking disciplines do not need to participate in instruction.

Keywords: information literacy education, undergraduate engineering education, mechanical engineering, environmental engineering, sustainability science, research accomplishment

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This period of more than three years has been a time of intense learning both academically and on personal level. Working on this dissertation has taught me a great deal about the research environment in which my customers work. I have also learned a lot about myself; how I manage stress, haste, and especially uncertainty and yet survive.

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I started this project when my children, Anna, Lauri, and Jussi, had already grown up and lived their own lives. Thank you for your patience when your mother's mind was full of research ideas. I am so grateful for your support and proud of all of you. And my precious grandchildren, Topias, Loviisa, Verner, and Inkeri, I wish to be able to be more present in your lives in the days to come. The purpose of this work is to benefit future information seekers and users, like you.

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Marja Talikka
May 2018
Lappeenranta, Finland

This thesis is dedicated to my children and grandchildren.

And lamenting and sorrow won't help, but work and action will. Onward now, brother!
-Aleksis Kivi

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Abstract

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1 Introduction

Growing awareness and concern of the Earth's sustainable development is discussed globally in various contexts. What humanity can and should do to stay within the boundaries of the sustainability tolerance of our planet is debated among politicians, scientists, and the general public. According to Rockström and other scientists (Rockstrom, Steffen et al. 2009, Hughes, Carpenter et al. 2013, Clift, Sim et al. 2017) humanity needs to understand its dominant role in the operation of the biosphere and how it shapes the Earth's systems.

What are the sustainability challenges that humanity faces? According to Portney (2015), sustainability focuses on the use and depletion of natural resources. It differs from environmental protection or natural resource conservation. Alternatively, it aims more at finding a steady state so that the Earth can support both human population and economic growth. In literature we can find challenges relating to a wide variety of issues including environmental sustainability (Dagiliute 2015), business needs (Veleva 2015), food production (Chowdhury 2017), urban development (Joss 2010, Swapan 2016, Freeman, McMahon et al. 2017, Waite, Cohen et al. 2017), and education (Zidanšek 2007, Biberhofer 2017). Zidanšek also argues that in order to achieve sustainable development humans must maintain and increase their happiness. The freedom of actions and the call for sustainable responsibility of individuals should be increased simultaneously. Moreover, Zidanšek says that sustainability aspects and values should be integrated in education. Furthermore, Escobar-Tello (2011) studies the relationship between happiness and sustainable design. She points out that necessary material changes can take place without having to do without social networks, which feed our happiness.

In the future, as the human population on the Earth keeps increasing, more and more people live in cities. In 2010, Joss (2010) published a review about sustainability issues in connection with cities. He discusses eco-cities, a phenomenon which can be traced to the 1980's. During the years, the concept developed from ideas about urban planning to

integrated public transportation and, in late 2000, globally appearing various initiatives towards low-carbon economy and the greening of cities. Towards mid-2010's, the focus appears to move towards resilient cities, sustainable consumption, energy demand, water and waste issues, and green manufacturing (Freeman et al. 2017, Mangla, Govindan et al. 2017, Tiwari, Adamowski 2017, Waite et al. 2017, Dixit, Hazarika et al. 2017).

To maintain the viability of the Earth, there is a need to focus more on environmental, economic, and social sustainability (Ferrara 2017, Mälkki, Alanne 2017). The change does not develop by itself. It requires a change in the mindset (Klein 2016) of higher education educators and students within all disciplines. For example, in the field of engineering, designing a specific product to fulfill a particular technological need is no longer wholly adequate. It is additionally necessary to take into consideration the conditions in acquiring raw materials, the context in which the product is manufactured and used, and to understand the effects that the product has on the environment and society during its production and operational lifetime.

For future engineers to be able to design and produce sustainable engineering solutions for the modern society, engineering education must become more interdisciplinary and include sustainability issues in the curriculum (Biberhofer 2017). Study assignments must be widened to cover not only the traditional design tools and methods but also sustainability challenges. To solve their design problems, students need to find information on their own discipline and connect sustainability aspects to it. To succeed in that they need guidance from their educators who represent relating disciplines.

Finding information is challenging in the increasingly complex information source environment. Adding the interdisciplinary aspect to the studies makes finding adequate and comprehensive information even more difficult. Information literacy (IL) education is included in the higher education (HE) engineering curricula to provide students with tools for finding, evaluating, and using information in their assignments and later in their working life. Students who study to qualify in modern working life need faculty teachers'

support in learning about interdisciplinary substances. To understand and utilize the complex information environment they need help from the library personnel.

The concept of information literacy has been introduced already decades ago to describe the skills students must have to be able to recognize their information needs, to find the right kind of information, to be able to evaluate the information, and to use it legally and ethically in their studies (ACRL 2000). Characterizations of information literacy have changed from underlining skills (Rader 2002, Johnston, Webber 2003, Gibson 2008, Maybee, Bruce et al. 2013) to focusing on creating new knowledge on the basis of the retrieved information. This change in understanding the concept can be seen in the new ACRL 'Framework for Information Literacy for Higher Education', which presents the creation of new knowledge and understanding the value and use of information as fundamental to IL learning outcomes (ACRL 2015).

In *The Seven Faces of Information literacy* (Bruce 1997), the author introduces some concepts which influence and coexist with information literacy. One of them is information technology literacy ITL, which is defined as "the knowledge which allows an individual to function efficiently and effectively in whatever circumstance one finds him/herself in a technologically oriented society". At present, features of the same kind can be associated with the concept digital expertise (Morrell 2012).

1.1 Background and motivation

In the fields of engineering, research problems often address very concrete issues. For example, in mechanical engineering many design-related tasks were solved earlier by simply finding a suitable standard for the structure (Wojciechowski 2000, Addis 2016). With the development of new advanced materials, this procedure does not apply any longer. The standards that were practical before may have based on one specific material which is perhaps not the most suitable one or not even available any more. To be able to do design work, an engineer or engineering student needs to search information about the new material properties to be sure that they apply to the same use and fulfill the present

economical, resistance, and ecological requirements. Moreover, in engineering fields, which increasingly contain elements of sustainability the questions have also become more complex and information needs are multidisciplinary (Wagner, Roessner et al. 2011).

According to organizations like ASIIN (Accreditation Agency for Engineering, Informatics and Natural Sciences), EUR-ACE (EUROpean ACcredited Engineer), and ABET (Accreditation Board for Engineering and Technology) which work for assuring and strengthening the quality of academic engineering education, the key learning outcomes in the section ‘knowledge and understanding’ for both Bachelor’s and Master’s program students are knowledge in mathematics, science, and engineering. However, according to ABET the Mechanical Engineering major produces graduates who demonstrate also *“an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability”* (O’Hern 2012) while ASIIN states that students should gain the *“ability to responsibly apply and independently consolidate their knowledge in different fields under consideration of economic, ecologic and safety requirements as well as sustainability and environmental compatibility”*. In general, they point out that understanding multidisciplinary contexts and the ability to function on multidisciplinary teams are necessary learning outcomes. On Master’s level, students should also show critical awareness of the latest findings in their discipline (EUR-ACE 2008, ASIIN 2011, O’Hern 2012).

All the mentioned accreditation organizations also state that engineering graduates should *“demonstrate ability to recognize the need for and to engage in independent lifelong learning”* (EUR-ACE 2008, ASIIN 2011, O’Hern 2012). Wertz et al. (2013) argue that information literacy is a critical component of lifelong learning, i.e. the ability to identify the need and goals for learning, as engineers need to renew their knowledge continuously. Tag et al. (2006) present a librarian-faculty collaboration model where IL education is integrated into an undergraduate class. Although it is not an engineering but a political

science class, the study presents how the course challenged students to explore their place in and responsibility to the global society and thus they explored their own relationship to selected global issues and learned some IL skills that can facilitate lifelong learning.

Modern research and design problems seldom involve purely one discipline. Therefore, solving them requires cooperation with colleagues representing other disciplines. However, bringing together the expertise of different experts in a multidisciplinary group may not always be sufficient. To solve complex problems, interdisciplinary attainments are needed. This means that each participating individual should have the ability to focus on the problem not only from their own discipline's viewpoint but he/she should also understand the principles of other disciplines involved in the matter (Wagner et al. 2011).

In *Figure 1*, examples of interdisciplinary information needs are presented in cases when both mechanical engineering and sustainability are involved. The illustration applies Fava's sustainability maturity curve (Fava 2014, Burgess 2014) which consists of four sustainability categories to show how mechanical engineering problems can be linked with sustainability. The curve can be used to help the searcher position the depth of his/her comprehension of the subject and the information needs. In the figure, Fava's first step *Complying* deals e.g. with laws, regulations and properties. *Market driven* is a step where e.g. more information on environmental, economic, and social issues is needed to satisfy user needs. *Engaged* and *Shaping the future* represent deeper maturity of sustainability, enabling the individual to undertake necessary actions pro-actively. Alternatively, mechanical engineering issues are presented from technical problems on the left to sustainability-related ones on the right. Students' research problems stand somewhere along the continuum. To find required information to solve the problems they need to be able to place them in the correct context.

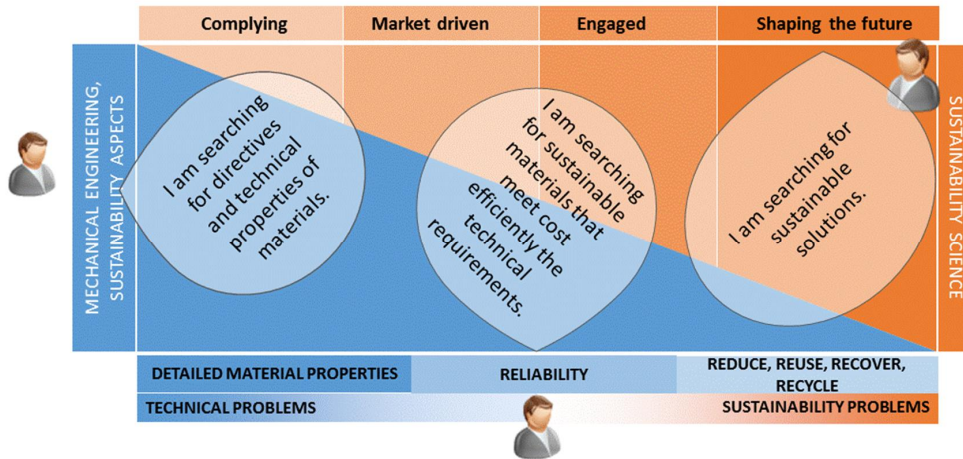


Figure 1 The characteristics of mechanical engineering information search problems vary based on the depth of their relationship to sustainability

At the same time when the awareness of factors threatening sustainability is rising (Rockström 2016), digitalization increases in most fields. Digital expertise (Reuter 2016) and information literacy (Taraban 2011) are needed to manage computerized design tool sand diverse and mostly electronic information resources. Students who study to qualify in modern working life need faculty teachers' support in learning about interdisciplinary substances. Moreover, to understand and navigate in the increasingly complex information source environment and to find and utilize information related to their research problem they need guidance from other experts (Koot, Mors et al. 2016, van den Boer, Arendsen et al. 2016, Bury 2016).

In mechanical engineering, materials selection is usually based on finding the appropriate material property profile, which corresponds with the requirement profile of the application. In many cases, optional materials are also searched and compared. Effective IL education is able to assist in finding references, which describe in detail the application requirements, present the material properties for the desired material property profile, and cover the selected or alternative materials. In addition to this, these three different

reference types can be at least partially overlapping. Figure 2 presents an example of how IL education supports the systematic materials selection process. This is used as the viewpoint of this research.

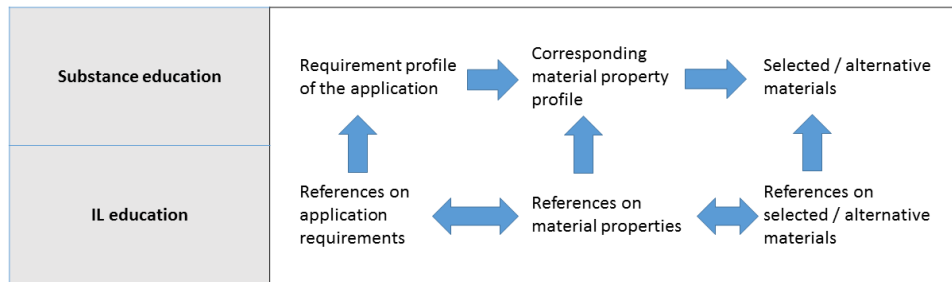


Figure 2 The role of IL education in intervening materials selection at various stages.

Students' research problem formulation processes start with the definition of the desired framework and viewpoint, inside which the research problem is established. The research questions are derived from the problem. These definitions include also some restrictions in making it possible to handle the research topic. IL education is connected to the establishment of the framework and the viewpoint by advising to select and to use appropriate information sources. The viewpoint, research problem, research questions, and possible restrictions are connected with the information search questions, which define the progression of the literature search. The research question formulation can be supported by analyzing the relevant references' amount and content during a specific time frame e.g. by using database tools for analyzing the result. This chain is described in Figure 3.

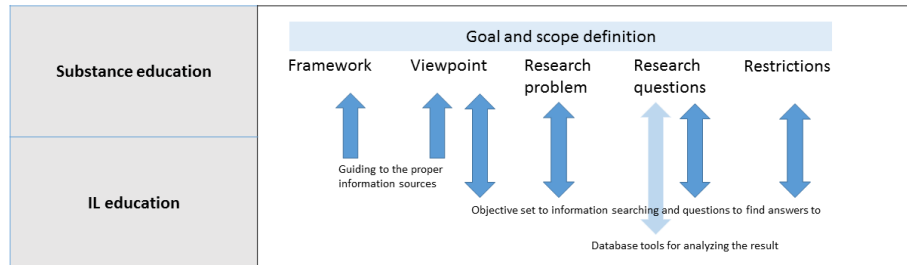


Figure 3 The role of IL education in supporting the substance education research assignment process.

To answer to students' every day information needs, IL education is part of higher education engineering students' curricula. There are different ways of arranging the education (Hepworth 2000, Johnston, Webber 2003, Owusu-Ansah 2004, Mery, Newby et al. 2011, Cisse 2016). While in some universities the library offers comprehensive courses on information retrieval and use, other institutes do it in more modest ways depending on the available resources. At LUT, IL education is mostly given by information specialists. IL teaching resources are, however, very limited and they must be used as efficiently as possible. Therefore, IL education consists of brief sessions and it is integrated into substance teaching (Talikka, Eskelinen 2013).

1.2 Research problem

At LUT, IL teaching resources are very limited. Therefore, Lappeenranta Academic Library (LAL) uses an IL education practice, which consists of brief, discipline-specific, productized IL education sessions with standard basic content. This kind of IL education is integrated into undergraduate engineering curriculum courses both on Bachelor's and on Master's level.

The original objective of this study was to find a solution to a small university library's problem: how to teach, with limited resources, the necessary information literacy skills to a growing student population. Separate, credit-bearing IL courses arranged by the

library were not an option. First of all, the library is not a unit that is allowed to offer credit-bearing courses within LUT. Secondly, even if LAL were allowed to offer IL education as separate courses within the curricula, the library's resources would not meet the need. Therefore, IL education had to be arranged some other way. One of the benefits of a small university is that teachers and library personnel meet in unofficial occasions and are thus able to discuss common problems. During those discussions, it was revealed that IL education sessions could be arranged as integrated lectures within some faculty courses.

This research concerns the Mechanical Engineering and Environmental Technology programs. Brief IL education was integrated in undergraduate engineering students' seminar course on which students were supposed to find a solution on a materials selection problem for a given application. According to the research assignment, students were advised to find, via literature search, the optimal solution from both mechanical and sustainability engineering viewpoints. It was not yet known what kind of effect the brief integrated IL education had on higher education engineering students' information searching and further on their research behavior and research accomplishments. Moreover, it was not known how the global sustainability challenges, the increasing digitalization of the information environment, and the development in engineering education which focuses more and more on wider entireties and interdisciplinary issues should be taken into consideration in information literacy education which has traditionally concentrated on teaching searching skills and presenting different information sources.

This study started with the aim to find out how brief integrated IL education sessions affected students' ability to find adequate and right kind of information for their research assignments, which concern sustainability, challenges within their own field, in this case mechanical engineering. During the study, it became obvious that in addition to teaching search skills i.e. finding and combining search words and determining where to search in order to find proper information, students' research expertise also needed improvement.

Therefore, the focus of this study sharpened to researching the impact of brief integrated IL education on the way students managed their research task and on how they combined their own discipline and sustainability engineering in their research.

In literature, the term ‘research skills’ is generally used to mean finding and using information in the particular research context (van der Schee, Rijborz 2003, Larkin, Pines 2005, Currie, Devlin et al. 2010, Henderson, Nunez-Rodriguez et al. 2011). However, for successful research, students also need the ability to understand the research problem in its interdisciplinary context and the knowledge of how information should be searched and used to solve that problem. This requires widely recognized understanding about information literacy, which in this study is referred to as *IL mindset* (Talikka, Soukka et al. 2018). The concept of mindset can be defined as “*a belief that orients the way we handle situations — the way we sort out what is going on and what we should do*” (Klein 2016). IL mindset can be viewed from three perspectives: the student’s, the teacher’s, and the engineering program’s viewpoint. From the student viewpoint, IL mindset can be described as global understanding about the whole research problem and knowledge of what kind of information is needed to solve it together with knowing how to utilize available information sources and search techniques. The teacher’s perspective to IL mindset consists of the equivalent ideas but the emphasis is on instructing the attainments to the students via pedagogical means. From the engineering program’s perspective, IL mindset means including necessary interdisciplinary elements in the curriculum to meet the requirements which modern engineering sets on higher education. In this study, student IL mindset development as a result of brief integrated IL education is discussed in order to find targets and ways for developing the curricula.

1.2.1 Research question

The research question in this work was:

How should the higher education engineering program curricula be developed to provide students with the IL mindset, which is needed to achieve learning outcomes, required for modern interdisciplinary, sustainability emphasizing engineering research?

The hypothesis of this study is:

The characteristics and content of information needs vary among different disciplines. Modern engineering design tasks are in most cases interdisciplinary. In engineering education, this is taken into account in planning both the program and the course contents by including interdisciplinary aspects in student curricula. Information literacy education helps students in understanding the interdisciplinary nature of their information needs and guides them to find the right kind of information for their assignments as illustrated in [Figure 1](#), which presents the role of IL education in the mechanical engineering and sustainability science context.

1.3 Research methods

The study was carried out by collecting data from student surveys, teachers' evaluations, students' papers, and higher education program evaluation matrices. The qualitative analyses of the data were performed by using text mining, a statistical method for turning text into numbers i.e. to extract information from texts by meaningful numeric indices (StatSoft Inc. 2013), to study the occurrence of meaningful words in students' interview answers and seminar papers, bibliometric observation (Marx, Bornmann 2016) which in this case was applied by evaluating the scientific levels of cited documents and their printing years (Talikka, Eskelinen et al. 2014), and by analyzing the content of students'

answers according to literature-based classifications created for this research. Classified qualitative data were quantified in order to observe the occurring processes.

The method triangulation for studying the impact of IL education on students' searching skills and research understanding consists of the following three elements: 1) evaluating the significance and impact of references, 2) analyzing the interviews and surveys based on the qualitative analysis according to Miles and Huberman (1994), and 3) learning outcome evaluation based on ASIIN (2011) and ABET (O'Hern 2012) engineering education quality assurance criteria and the ACRL information literacy framework (ACRL 2015). Out of the three qualitative data analyzing approaches, the social anthropology or recursive approach is used here. The recursive approach was selected because it suits this kind of analysis of data when human behavior is studied by e.g. coding and sorting data from interviews and surveys (Savenye, Robinson 2001).

1.4 Scope

The scope of this study is to find out how brief IL education, which is integrated in engineering substance education, affects students' research accomplishments. In addition to studying changes in students' information searching and use, the research concentrated on the development in students' ability to understand their research problems and on their respective information search questions. The study focuses on brief, one or two-shot, integrated IL education. Wider e.g. credit-bearing IL education models are not discussed because they are not possible in the Lappeenranta University of Technology (LUT).

In this research, the effects of IL education were studied on three kinds of courses. Seminar courses in the LUT Mechanical engineering program consisted of research assignments on materials selection for a given application in a given environment. The emphasis on their task was that the solution of the problem should also support sustainable development. The students on the Basic course of environmental technology completed a narrower study where their task was to find environmental aspects along the life cycle of a product or service. On the Research methods and methodologies course students

produced a research plan for their topic. Interdisciplinary technological and economic expertise is LUT's starting point in seeking scientific solutions to sustainability problems (Lappeenranta University of Technology 2012). Therefore, concentrating on these fields of science was appropriate for this research. Other fields of science represented at LUT fall outside the scope of this research. However, LUT School of Engineering Science and LUT School of Business and Management can be studied later.

The studied courses represent the core areas of modern engineering. The studied groups were students from Bachelor's level environmental engineering (Talikka et al. 2014) and from Master's level mechanical engineering who focus on sustainability challenges (Talikka, Eskelinen 2013, Talikka et al. 2014, Talikka, Eskelinen et al. 2015). Moreover, the studied groups represented both Finnish and international students at Bachelor's and Master's level.

In order to get comparable results, the outline of the IL education module content was designed according to previous research results of problems, which students experience in information retrieval. The same basic module with minor discipline-based tailoring was used in teaching all the researched courses.

To pre-examine the possible changes appearing in students' research accomplishments as a result of brief integrated IL education, a pilot study was performed on two Master's level mechanical engineering courses (Talikka et al. 2014). On subsequent two full-scale courses, a classical research setup was used. Students on those courses were divided into the research groups, which attended IL education, and the comparison groups, which did not attend. The results were viewed from three viewpoints: significance and impact of used references i.e. in this case citation analysis (Marx, Bornmann 2016), qualitative analysis of survey and interview answers according to Miles and Huberman (1994), and learning outcome evaluation based on ASIIN (2011) and ABET (O'Hern 2012) engineering education quality assurance criteria and the ACRL information literacy framework (ACRL 2015). To study the effect of brief integrated IL education on students' research question and their information search question formulation the entire third full-

scale course was observed as one research group. For analyzing their interview answers, classifications based on literature (Kuhlthau 1993, Vakkari 2000, Ackoff 1989, Fava 2014, Burgess 2014) were generated for this research.

1.5 Contribution

This research produces new scientific knowledge about the effects of brief integrated IL education on higher education students' research abilities. The focus is on undergraduate mechanical and environmental engineering students. Engineering students often search information for their study assignments without sufficient consideration of the context of their research topic. This study discusses how students' IL mindset, i.e. students' understanding of research problems and formulation of information search questions, develops through integrated IL education. In addition to improved information searching skills, students' interdisciplinary research problem descriptions became more profound and their formulations of information search questions showed more advanced understanding of the principles of information use.

2 Literature review

2.1 Sustainability in engineering education

Along with the industrial revolution in the 19th century, the importance of mechanical engineering increased remarkably. In those days, mechanical engineering applications appeared mainly in transportation solutions, power generation, and military products. At present, mechanical engineering contributes e.g. to the production and maintenance of biomedical device and robotics. Within chemical industry, thermodynamics, heat transfer, and fluid mechanics are significant mechanical engineering aspects. Moreover, incoming mechanical engineering fields like nanotechnology and synthetic biology are emerging increasingly to new technological solutions. (Dixit et al. 2017)

At present, the role of mechanical engineers is crucial in sustainable development. The vision of the future consists e.g. of responding to the global environmental pressures by developing new technologies and techniques, engaging in international collaboration around critical knowledge and competence, and working on providing Bio-Nano-based solutions for fields like healthcare, energy, and environmental management (Zamrik 2009). Therefore, mechanical engineering students must be trained to have appropriate knowledge to understand interdisciplinary issues in connection with their own discipline.

Quality assurance accreditation organizations audit higher education engineering programs according to their specific criteria. As competence in the area of knowledge and understanding, ASIIN (2011) emphasizes “extensive advanced knowledge of mathematic-scientific and engineering principles of mechanical engineering / process engineering / chemical engineering and their interdisciplinary expansion as well as a critical awareness of the latest findings in their discipline”. Respectively, ABET (O'Hern 2012) states that the following abilities are needed to solve subject-specific problems creatively by using subject-specific knowledge, skills, tools and methods: 1) to apply knowledge of mathematics, science, and engineering, 2) to design and conduct experiments, as well as to analyze and interpret data, 3) to design a system, component,

or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability, 4) to identify, formulate, and solve engineering problems, 5) to understand the impact of engineering solutions in a global, economic, environmental, and societal context, and 6) to use the techniques, skills, and modern engineering tools necessary for engineering practice. (May, Terkowsky 2016)

Both ASIIN and ABET refer to interdisciplinary issues and ABET also clearly mentions the demand for understanding sustainability. According to Wagner et al. (2011) *‘Interdisciplinary approaches integrate separate disciplinary data, methods, tools, concepts, and theories in order to create a holistic view or common understanding of a complex issue, question, or problem. The critical indicators of interdisciplinarity in research include evidence that the integrative synthesis is different from, and greater than, the sum of its parts.’*

Vinodh et al. (2014) argue that the design stage of product development is significant for determining cost, profitability, and environmental impacts of the product. Embedding sustainability issues in mechanical engineering curriculum ensures that the latest sustainability knowledge can be delivered to the future engineers (Vinodh et al. 2014).

In 1987, the World Commission on Environment and Development (Brundtland 1987), the so-called Bruntland Commission, stated that sustainability is economic-development activity that “meets the needs of the present without compromising the ability of future generations to meet their own needs”. According to the Bruntland Commission report, sustainability has three co-equal elements: environment, economy, and equity and sustainability can be achieved only by simultaneously protecting the environment, preserving economic growth, and promoting equality. Nearly 30 years later, Portney (2015) stated that sustainability focuses on the use and depletion of natural resources. The aim of sustainability is to find a steady state so that the Earth can support both human population and economic growth. Consequently, Shahadu (2016) defines sustainability

science as ‘*a problem inspired, interdisciplinary science of systematic enquiry into the interconnections and relations between the past, present and future of life and its support systems, with the goal of keeping the productive capacity of life support systems in harmony with the demands placed on them, at all times*’. This definition is based on a literature review, which aims at finding a definition for the discipline.

The boundaries of the sustainability tolerance of our planet are presented e.g. by Rockström (2015), who claims that an integrated social, environmental, and economic perspective is imperative to maintaining the planet’s stability. Rockström further argues that humanity needs to understand its dominant role in the operation of the biosphere and how its activities shape the Earth’s systems. The interdisciplinary role of maintaining the viability of the Earth is clearly seen in the Planetary Boundaries framework (Clift et al. 2017). The framework conceptualizes the ecological limits to human development and the risks caused by unsustainable production and consumption. The four scientific and technical challenges which are preferential in future research are the

1. climate change,
2. the ‘distance from boundary’ approach,
3. development of global, preferably open-source, databases and models,
4. and designing fair-share principles (Clift et al. 2017)

Consequently, sustainability research extends across numerous disciplines of the humanities, the social sciences, and the natural sciences, and therefore IL education, especially in higher education institutions where students undertake research as a part of their studies, faces the challenge of widening students’ views of their information search questions to contain sustainability aspects in addition to their own field of science. Moreover, the global trend of promoting and favoring open science and open access information is imperative for supporting decision-making in companies and other organizations in their objectives to respect absolute sustainability. (Clift et al. 2017)

2.2 Information and information literacy

What does the concept of information actually mean? Russell Ackoff (Ackoff 1989) defines that the concept can be divided into categories based on their status of added-value. To clarify the substance of information, Ackoff's knowledge hierarchy is used as a basis. According to Ackoff, data are symbols that represent the properties of objects and events. Information which consists of processed data provides answers to questions like *who*, *what*, *when*, *where*, and *how many*. Processed information is called knowledge, which answers *how-to* questions e.g. 'how a process should be carried out to minimize energy consumption'. Understanding is the next notion in the structure. This concept answers *why* questions like 'why does a specific aspect of saving energy work as it does'. According to Ackoff, the pinnacle in the hierarchy is wisdom, which, unlike the lower level concepts, is dependent on the judgement of the actor.

The concept of information literacy has been introduced already decades ago. According to Bruce (1997), descriptions of IL date back to the 1970's. There are a number of documents, which deal with the history of the term (Johnston, Webber 2003, Rader 2002, Gibson 2008). Bruce (1997) also presents concepts, which influence and coexist with information literacy namely information technology literacy ITL, computer literacy, learning to learn, information skills and library skills. *ITL* was defined by Penrod and Douglas as "the knowledge which allows an individual to function efficiently and effectively in whatever circumstance one finds him/herself in a technologically oriented society" (Allen 1986). ITL changes from person to person depending on the situation. Kuhlthau (1987) defines information literacy as a combination of library skills and *computer literacy*, which means understanding what computer hardware and software, can do. Kuhlthau also presents the term "information illiteracy" which, according to Carol Kuhlthau, cause real harm to individuals and to society. Keeping in mind that her book was published already in 1987, she brings out outstandingly up-to-date questions about learning when she argues that "Learning to question, to weigh alternatives to interpret inferences, and to seek further data can only help individuals to cope with a continuously

increasing wealth of information, and to survive in a world growing ever more complex” (Kuhlthau 1987). *Learning to learn* (Bruce 1997) is connected with self-direction in learning and lifelong learning but it is not equal to learning to study or acquiring study skills. The concept of *Information skills* (Bruce 1997) dates back to the mid 1980’s and it can be “said to focus on the intellectual processes of information use”. *Library literacy* means simply the ability to use libraries (Bruce 1997). Bruce argues that all the previously mentioned concepts are discrete but yet interrelated.

According to Johnston and Webber (2003), the roots of the information literacy concept are in “library skills” i.e. knowing how to find material in the library and in the ability to use information technology in one’s work. In different parts of the world, IL has been seen in diverse ways. In the US in 2000, the Association of College & Research Libraries (ACRL) published their first information literacy competency standards for higher education (ACRL 2000). In that document, IL was defined as students’ abilities to recognize when information is needed and to locate, evaluate, and use the information legally and ethically. Australians, at the same time in their own IL competency standards, focused more on constructing and extending knowledge and understanding and acknowledging e.g. the cultural issues surrounding the use of information thus going beyond the emphasis on library skills and information technology (Bundy 2004). Meanwhile, in the UK IL was seen more like a contribution to create new knowledge via synthesizing and building upon information (Johnston, Webber 2003). In the early 2000’s, Finnish universities’ IL education was generally carried out following the ACRL standards. Nevertheless, all the early approaches saw IL education as a separate component within HE curriculum without an intensive connection to substance education.

Although the role of the original ACRL Information literacy competency standards has been remarkable ever since they were published, there has also been a lot of discussion about how they apply to the changing educational environment. According to Johnston and Webber, information literacy can be seen as a response to the cultural, social and economic developments associated with the information society. They also mention that

already in 1994 in a report on lifelong learning, P.C. Candy, G. Crebert and J. O’Leary (1994) make information literacy one of the five key elements in the profile of a lifelong learner (Johnston, Webber 2003). Johnston and Webber see, however, a danger. Whilst the ACRL approach seems to emphasize the role of the individual, the result is a series of detailed lists. They see a “*danger that a strategy like that of ACRL results in a ‘tick the box’ approach: reducing a complex set of skills and knowledge to small, discrete units.*” (Johnston, Webber 2003)

A few years later, Owusu (2005) states that proponents of information literacy know that IL is not a fixed, final destination. They know what abilities and fluencies to expect of individuals with varying levels of information literacy. Competency and fluency represent degrees of higher achievement along a continuum of accumulating skills, familiarity, and efficiency. Debate over definitions like information literacy, information competency or information fluency gives no practical benefits. Such activities can become waste of time and energy which could be spent on working to improve student capabilities, on exploring the role which the library can play in that process, and on determining the legitimacy and desired extent of the library’s participation in the education of information literate students.

In 2013 the content of the original ACRL competency standards needed extensive revision. According to Banks (2013) the revision must take place because the Internet had profoundly altered the ways of creating, sharing, analyzing and validating information. To be credible, the new ACRL standards needed to take this change in serious consideration.

During the fifteen years after the first ACRL competency standards, the development of the information environment as well as new tools and learning outcome expectations which had arisen brought a need to integrate modern IL concepts and skills into students’ curricula. Over the years, higher education programs had developed in many ways. On more and more courses, students were expected to create new knowledge as part of their

assignments and therefore had to be taught to understand the value and use of information. Teachers, on the other hand, needed to reform curricula and assignments to utilize the core information within their disciplines. As for librarians, it became necessary to be able to promote students' learning by creating new curricula for information literacy in collaboration with faculty. Because of this development, new Framework for Information Literacy for Higher Education was created and published in February 2015 by ACRL (ACRL 2015).

Additionally, the new Framework discusses metaliteracy (Mackey, Jacobson 2014), which is a new vision of IL. It is seen as a set of abilities needed in consuming and creating information collaboratively. According to the Framework, *'metaliteracy demands behavioral, affective, cognitive, and metacognitive engagement with the information ecosystem'*. Moreover, the *Framework* emphasizes the need to become 'more self-directed in the rapidly changing ecosystem' (ACRL 2015). In connection with metaliteracy, the issue of transdisciplinary research can also be discussed. Wagner (2011) states that while transdisciplinary approaches are *'comprehensive frameworks that transcend the narrow scope of disciplinary worldviews through an overarching synthesis'*, the term also has a nuance of a new way of knowledge production i.e. integrating research from different disciplines with the knowledge of stakeholders in society especially in connection with sustainability. Wagner argues that the transdisciplinary product is greater than the sum of its parts. Alternatively, Lang et al. (2012) define transdisciplinarity as *'a reflexive, integrative, method-driven scientific principle aiming at the solution or transition of societal problems and concurrently of related scientific problems by differentiating and integrating knowledge from various scientific and societal bodies of knowledge'*. They discuss transdisciplinarity in connection with sustainability challenges which they argue that need actors representing different disciplines to be met.

2.3 Information and research competences

With the development of the Internet, more and more information has become directly available to end-users. Banks (2013) claimed that a revision of the ACRL standards was needed because the Internet had profoundly altered the ways of creating, sharing, analyzing and validating information. However, Head (2013) argued that many students lack comprehensive understanding what the information search process is about. Students use Google and some other familiar information sources but do not know the logic of the operation of search engines.

At present, the price, usability, and efficiency of personal digital equipment have developed so that students can use their own laptops and mobile device to acquire information from digital and digitized online information sources which, alternatively, have become more applicable to information users. Therefore, or perhaps to encourage this development, universities and university libraries have started cutting the available digital equipment resources and induced students to bringing their own device to class and to the library. BYOD (bring your own device) (Bernadette Buljung, Gale Cooper 2013, Walton 2014) became the order of the day.

Apart from digital equipment development, the information field also changed. During earlier years, the availability of source information for research was behind passwords or information was accessible for only those using the allowed Internet Protocol (IP) addresses. In 2010's, especially after 2014, open science with open access documents is taking over the publishing field thus allowing researches reach and use documents more widely than ever (Frederick 2016). At the same time, disinformation spreads like weed. Therefore, evaluating information and its source no longer means just observing the suitability of the retrieved information to extend the searcher's knowledge of the topic. Analyzing the genuineness of the information, the authenticity of the source, and how well it answers the question at hand have become an essential part of information evaluation.

Lambrechts and Van Petegem discuss the interrelations between competence for sustainable development and research within higher education institutions (Lambrechts, Van Petegem 2016). They call for a holistic view of research competencies, which comprise knowledge, skills, attitudes, and values. Information literacy enables students to cope with different information sources in a complex and uncertain context of sustainability issues both in their studies and in society. However, IL is often seen as a separate set of competencies within higher education (Johnston, Webber 2003).

2.4 Information literacy education

ACRL defines IL in the new Framework for Information Literacy for Higher Education as follows: *“Information literacy is the set of integrated abilities encompassing the reflective discovery of information, the understanding of how information is produced and valued, and the use of information in creating new knowledge and participating ethically in communities of learning”* (ACRL 2015). The Framework consists of six concepts, which are central to IL:

- Authority Is Constructed and Contextual
- Information Creation as a Process
- Information Has Value
- Research as Inquiry
- Scholarship as Conversation
- Searching as Strategic Exploration

Modern IL education strives to incorporate these concepts in curriculum planning. The concepts, however, do not emphasize sufficiently one important aspect of information literacy: All information retrieval has its basis in the research problem. In order to succeed in finding the right kind of information it is indispensable to determine and understand the research problem and to define the information search questions for finding information needed for solving the problem. (Talikka et al. 2018)

As mentioned before, the 2015 IL framework also discusses abilities needed in collaborative consuming and creating information, i.e. metaliteracy (ACRL 2015). While in the sustainability science viewpoint, collaboration between experts representing various disciplines is essential (Vincent, Dutton 2016), future engineers – representing both sustainability and other engineering fields -- should learn to collaborate with colleagues who represent other disciplines. Moreover, from the IL viewpoint, they should all learn to utilize information from outside their own discipline. This challenges IL education to extend the discipline-specific view of the topic to include a wider perspective in information searching. In case of small universities and their libraries, this is even more challenging because of often very limited class-time.

Small university libraries often lack possibilities and resources to arrange separate IL courses. Short, one-shot IL sessions are inexpensive to arrange and are less labor-intensive. Webber (2000), Juntunen et al. (2008), and Cisse (2016) have reported research results of extensive study modules on one hand and of one-shot sessions on the other. Pausch and Popp (1997) argue that they are rather ineffective and claim that students are satisfied with the one-shot session only because they do not know enough to be dissatisfied. Julien et al. (2017) discuss the role of brief IL instruction sessions on the basis of a survey conducted among American academic librarians. They argue that librarians are frustrated by the view that sufficient information literacy can be achieved during a one-hour demonstration. Librarians want to be seen more as instructors with a high level of needed expertise. The authors report, however, that several respondents shared success stories of instructional partnership with faculty. Alternatively, Talikka et al. (2015) found that changes in students' information searching performance can be seen even after brief, 90-minute IL education sessions.

Järvelin and his colleagues (Järvelin, Vakkari et al. 2015) discuss task-based information interaction. Learning assignments in HE often require information interaction which they define as behavioral and cognitive activities related to task planning, searching and selecting information items, working with information items, and synthesizing and

reporting. To be able to do this in connection with their substance studies, students need to gain information interaction abilities and need therefore information literacy education. IL teaching resources appear to continue being limited in many institutions. Moreover, students are more motivated to learn IL attainments in connection with real learning contexts (Togia, Korobili et al. 2012). Therefore it is functional to integrate IL education into substance education to support students in the tasks they face in it.

3 Research methods

In modern engineering education undergraduate students often engage in doing research as part of their courses. To assist them in these tasks, information literacy education is included in their curriculum. In the studied university of technology, extensive information literacy courses could not be arranged. Instead, brief IL education sessions could be integrated to the curricula. The study concerns the effects of brief integrated information literacy education on undergraduate engineering students' research behavior. The objective was to find out if students' information searching skills, research accomplishments, and research understanding would benefit from the brief integrated IL sessions which based on previous findings about problems students face in information retrieval and use. The study was carried out on five seminar courses on which IL education was integrated as part of the course curriculum. Data were collected from student surveys, teachers' learning outcome evaluations, and students' final seminar papers. The collected survey data were analyzed by reduction, grouping, and abstraction and then quantified by following the Miles & Huberman method (Miles, Huberman 1994) as presented in Figure 4. Teachers' learning outcome evaluations consisted of students' grades and their information use in the final papers. Moreover, bibliometric analyses of used literature were performed in the seminar papers.

QUALITATIVE ANALYSIS OF OPEN INTERVIEWS

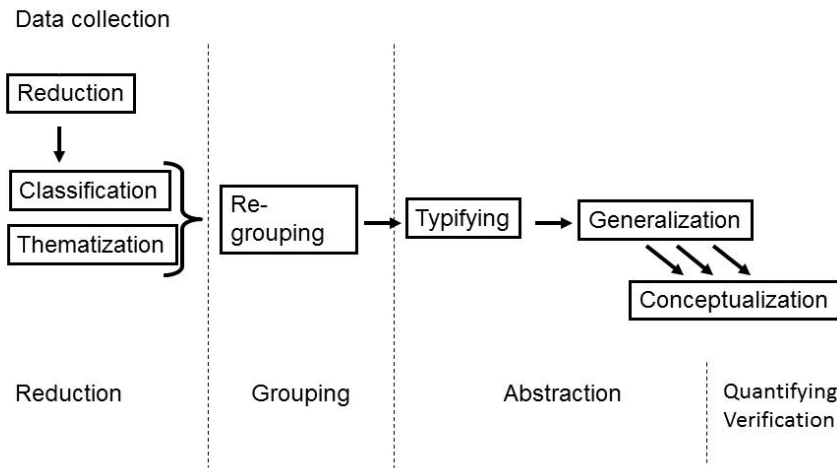


Figure 4 Qualitative analysis of open interviews by applying the Miles and Huberman method (Miles, Huberman 1994)

3.1 Applied research methods

3.1.1 Principal research structure

The overall picture of the applied research methodology is presented in Figure 5. In this research, the classic set up with several research groups and comparison groups was used when changes in students' searching skills and research behavior were studied. Students were given a research assignment, which based on literary research. Before starting their work, all students answered questionnaires about their information searching plans and, with the exception of one course on which the research problem was given to them by the teacher, also about their research problem formulations. Randomly selected students attended IL education before starting their work and thus formed the research group. When students had completed their research tasks, the differences in their information literacy and research accomplishments were studied. A bibliometric evaluation of used

literature was done by analyzing the citations and how literature was used in students' final papers. Research group students answered surveys about their information searching and the definition of their research problem after IL education. All answers, both those given before the assignment begun and those after IL education were analyzed according to the Miles & Huberman method.

One of the studied student groups was observed to study in particular students' research problem formulation and development in information search questions. In this case, students were not divided into research and comparison groups but all students attended IL education. By filling questionnaires, they answered questions about their research problems and information searching plans and explained what the questions to which they aimed to find answers from the retrieved literature were. The answers were transcribed and then analyzed according to the Miles & Huberman method.

Observed learning outcomes were analyzed by substance and IL teachers and compared with desired learning outcomes in the ASIIN, ABET, and ACRL criteria.

An overall analysis of the integrated findings supported by relating views presented in literature was generated. The interpretation of the change in students' IL mindset was generated as a result of the findings. The results can be used to develop the IL education sessions and the entire IL curriculum.

The reliability of the overall analysis was verified by cross-tabulation of evaluations, by method triangulation, and by using Sink's criteria to check the reliability of the whole research methodology.

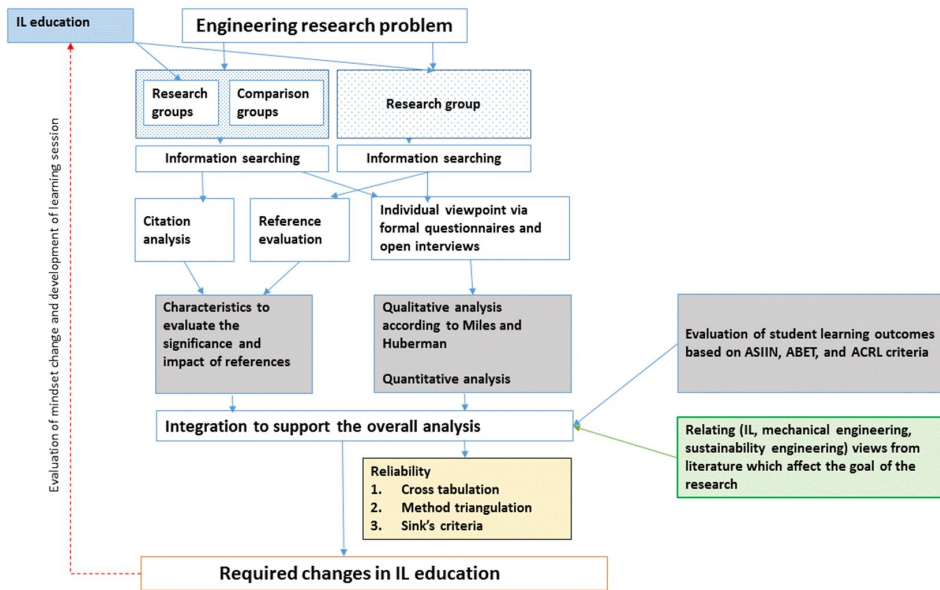


Figure 5 Overall picture of the research methodology

The method triangulation consists of 1) the evaluation of the significance and impact of references, 2) the qualitative analyses of student surveys according to Miles and Huberman (Miles, Huberman 1994), and 3) the evaluation of student learning outcomes based on ASIIN (2011), ABET (O'Hern 2012) engineering education quality assurance criteria and the ACRL information literacy framework (ACRL 2015).

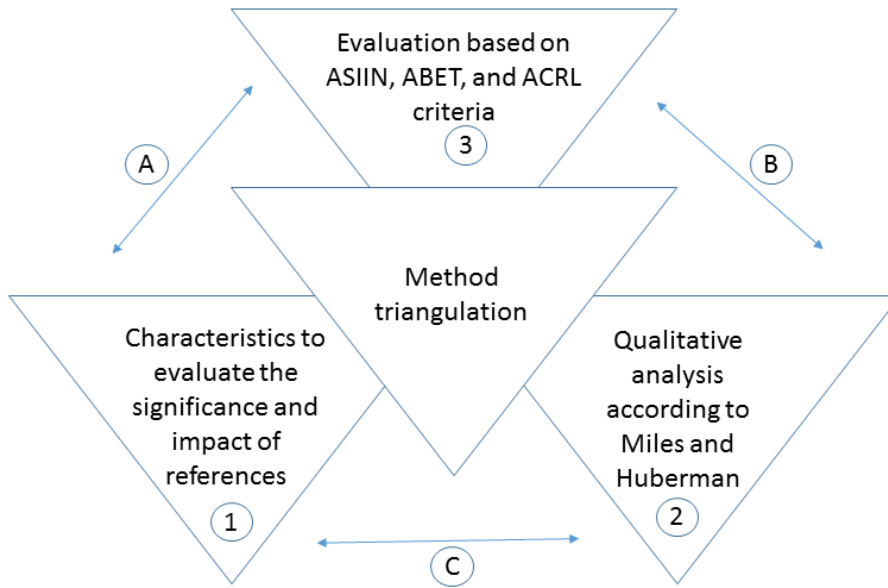


Figure 6 Method triangulation

3.1.2 Qualitative methods

The qualitative analyses of the data were performed by conducting citation analyses, by evaluating students' information retrieval exercises, and by analyzing the content of students' answers to questionnaires and interviews according to literature-based classifications created for this research.

3.1.3 Quantitative methods

Text mining was used in the cases when the numbers of used search practices and used meaningful terms in student' papers were calculated. Verifications of evaluations were done by applying cross-tabulation. Moreover, the results of qualitative analyses were quantified.

3.2 Practical arrangements

To make sure that the limited teaching time was used effectively and to find out what students know and don't know about information searching and thus to concentrate on the essential things in class, a formative pre-assignment has been used in LUT IL education since 2010 to determine the existing IL skills of student groups.

3.2.1 Formative pre-assignments

The first pre-assignment was conducted in order to find out about the existing IL skills of 12 Bachelor's level students. The questions were much the same as the ones Dunaway and Orblych (2011) presented a few years later. However, the assignment was not meant to be an exercise but to give the IL teacher information about the students' existing IL knowledge and to introduce information searching to the students before the classroom session. In the first experiments the reports were returned to the instructor by email. The answers gave good knowledge of what the students already knew and what they still needed to learn.

Gradually the number of seminar groups using the pre-assignment grew and it became too laborious for one teacher to read all the individual students' answers. At that point the idea to reduce the amount of answers by using student grouping and blend the pre-class part of the education in social media was tempting. There are examples of successful blended learning approaches to teach IL to large student audiences with limited library staff resource. One of them is presented by Fiona Ware (2011).

There were many social media tools that could be used. One freely available tool was EtherPad, a web-based collaborative real-time editor. EtherPad was chosen for this project because it is easy to exploit and requires no administration. When students worked in groups, they were expected benefit from collaboration. According to Laal and Ghodsi (2012), working together promotes learning. Using the described pre-assignment method, the social media tool allowed the students to see each other's texts and learn from them.

The content of the pre-assignment, which consisted of four tasks, is presented in Table 1. From the answers, the IL teacher found out about students' existing skills and knowledge. Based on that, the teacher could tailor the lecture material package by focusing on the issues, which were the most unfamiliar to the students. In addition to the pre-assignment and lecture in class, the IL education package also included a practice session, during which the students were instructed in searching information on their own subjects. All this required only one teacher who read the pre-assignment answers and gave the lecture and one or two instructors in the computer laboratory. (Talikka, Tahvanainen et al. 2013)

Table 1 Pre-assignment tasks (Talikka et al. 2013)

| Pre-assignment tasks | |
|----------------------|---|
| 1 | Find a scientific article on your seminar topic and show a link to it |
| 2 | Report how and where you found it |
| 3 | Tell about possible problems in information retrieval |
| 4 | Explain why you think the retrieved article is scientific |

The pre-assignment has been repeated tens of times with different student teams. The answers vary from team to team but some phenomena frequently appear. In all teams, finding suitable search words and limiting the search were considered as big problems. Moreover, deciding where to search is also mentioned frequently in students' answers.

To give an example, the results of one student group are presented below (Talikka et al. 2013). Students, in this case Bachelor's seminar students of business administration (n=160), used the EtherPad online tool for answering the questions and they worked in teams of five to eight members. There were 30 teams altogether. 57 per cent of the teams had problems in finding the right search words and/or in limiting the search so that they could filter the right and useful information out of a large number of retrieved references.

Finding suitable databases and right kind or reliable scientific information were considered difficult in 13 to 17 per cent of the groups. Some groups reported problems in using the English language or the scientific language in general while a few groups described that they had difficulties in information retrieval because they did not yet have a clear picture of their topic.

Table 2 presents the issues students reported difficult in information searching in terms of times they were mentioned.

Table 2 Difficulties in information searching (Talikka et al. 2013)

| Difficulties in searching | Times mentioned | Per cent |
|---|-----------------|----------|
| Finding search words | 17 | 57 |
| Limiting the search | 17 | 57 |
| Finding correct databases | 5 | 17 |
| Finding the right kind of information | 4 | 13 |
| Finding reliable scientific information | 4 | 13 |
| Don't know what to search | 2 | 7 |
| Finding the full text | 2 | 7 |
| Using the English language | 2 | 7 |
| Scientific vocabulary | 1 | 3 |
| Different operation of databases | 1 | 3 |
| Using the information retrieval portal | 1 | 3 |

An IL education lecture material package was created for this research. It consisted of the most important IL education contents for Bachelor's level based on the national IL education recommendations (The Council for Finnish University Libraries 2013). Moreover, the results of the pre-assignment analyses were used to include items that appeared to be the most important to the students according to their answers (Talikka et al. 2014).

The content of the IL education and the corresponding difficulties in information searching which the education aims to answer are presented in Table 3.

Table 3 Content of the IL education.

| Content | Meets the difficulty in searching |
|---|---|
| Characteristics of different information sources in general. Information sources applicable in this task. | Finding correct databases Finding the right kind of information Finding reliable scientific information |
| Selecting information sources for searching. | Finding correct databases Finding the right kind of information Finding reliable scientific information Using the information retrieval portal |
| Selecting search words, alternative words, effects of truncating, using abbreviations, differences between British and American spelling. Highlighting that in the search engine's viewpoint words are only strings-of-characters with no actual meaning. | Finding search words Limiting the search Using the English language Scientific vocabulary |
| Creating search queries by using logical (Boolean) and proximity operators, parentheses, phrases. Effects of different connectors on the result. | Limiting the search Using the English language |
| Using the available information retrieval portal (Metalib). | Finding correct databases Finding the right kind of information Finding reliable scientific information Limiting the search Finding the full text Using the information retrieval portal |
| Demonstration of searching in ProQuest, Science Direct, Scopus. The advantages of using databases' own user interfaces. | Finding the right kind of information Finding reliable scientific information Limiting the search Different operation of databases |
| Analyzing tool of Scopus, e.g. what the analysis of publication year, source, and subject area can show. | Limiting the search |
| Quality issues, e.g. impact factors. | Finding reliable scientific information |

3.2.2 Pilot and full scale research

The second study was a pilot research, which focused on the impact of brief IL education on students' searching behavior and research skills (Talikka et al. 2014). The pilot study concerned two classes: Construction materials (CM) seminar and Research methods and methodology (RMaM), which were Master's level courses. After that, a full scale research was performed in three student groups (A to C) to verify the pilot study results and to find out if integrated IL education would help students in understanding and formulating better their research problem (Talikka et al. 2015) and focus on the sustainability issues of their assignment. The classes and the objectives of the respective questionnaires are presented in Table 4.

Table 4 Studied groups and objectives of questionnaires presented to the groups

| | Course | Objective of questionnaire | Appendix |
|------------------|---|--|----------------------------|
| Pilot study | CM Construction materials seminar, Master's level course (n=7, response rate 100 per cent in three surveys) | Planned and actual information search methods and problems in information retrieval, differences between the research and comparison groups | Appendix 1 |
| | RMaM Research methods and methodology, Master's level course (n=23, research group n=8, response rates 61, 88, 50 per cent in three surveys) | Planned and actual information search methods and problems in information retrieval, differences between the research and comparison groups. | Appendix 1 |
| Full-scale study | Course A Selection criteria of construction materials, Master's level seminar course (n=48, response rates 66, 86, 62 per cent, three surveys) | Target mainly in changes in formulation of research questions and information search questions were studied, differences between the research and comparison groups. Focus on sustainability views. Development in searching and using information was also viewed. | Appendix 2 |
| | Course B The Basic Course in Environmental Technology, Bachelor's level (n=125, response rates 26, 73 per cent, two surveys) | Development in searching and using information, differences between research and comparison groups. | Appendix 3 |
| | Course C Selection criteria of structural materials, Master's level seminar course (n=38, response rates 89, 87, 82 per cent, three surveys) | Changes in formulation of research questions and information search questions before and after IL education were studied. Focus on sustainability views. Development in searching and using information was also viewed. | Appendix 4 |

Students worked in teams of four to five in this part of the study. In CM, RMaM, Course A, and Course B the answers were collected by the Webropol survey tool. All students attending the mentioned courses were questioned before IL education. Randomly selected half of the classes then formed research groups and they attended the IL education. Another questionnaire was given to them after the IL education. The other half of the classes formed comparison groups. The Webropol tool was used to send individual questionnaire links via email and the answers were collected and analyzed in Webropol. Text mining (StatSoft Inc. 2013) was used for finding descriptive terms in student answers. The terms were grouped and quantified for analyzing the answers. Illustrations of the results were generated by Webropol.

Changes in formulation of research questions and information search questions were studied on Courses A and C. The questionnaire to Course C students ([Appendix 4](#)) was given to the students in print and they wrote their answers in the forms. To verify earlier results about search words and search strategies, students were asked about them in the same forms. The answers were transcribed and the data were collected in Excel files. Classifications of given answers were stored and processed and the illustrations were worked in Excel.

Substance teachers' evaluations on pilot courses and on courses A and B were done without the teacher knowing which students were members of the research group and which ones were in the comparison group.

3.3 Numerical and statistical analysis

Verification of information search question classifications of students' answers on Course C was done by applying peer checking. Peer classifications were compared with the author's classifications by cross-tabulation.

Data acquired from printed questionnaires were transcribed, analyzed, and quantified in Excel.

3.4 Developed analyzing methods

A four-part classification was generated to categorize the depth of students' research questions. The classification is based on the knowledge hierarchy of Ackoff (1989). The sustainability maturity curve by Fava (Fava 2014, Burgess 2014) was applied to formulate the descriptions so that they suit this case. The categories were:

- I. Questions concerning recognizing the limitations in the use of materials (may concern legislation, technical standards etc.)
- II. Questions concerning the sustainability of chosen materials
- III. Questions focusing on the sustainability of the applicable material options and their benefits
- IV. Questions related to the most sustainable way to fulfill the needs of the application

The development of students' information search questions was evaluated. The six-point classification approach by Vakkari (2000), which is based on the model of the stages of information searching presented by Kuhlthau (1993) was applied in the evaluation. Together with this classification, the six cognitive process categories of Bloom's taxonomy (Anderson, Krathwohl 2001) were connected with Vakkari's definitions to link them to the profundity of students' understanding of the issues studied. The data were collected from surveys carried out at three stages of the IL education continuum: a) before the IL education, b) after the IL education, and c) after the seminar paper and poster writing processes had been completed. The categories used in the classification were:

- I. Initiation (Bloom's cognitive dimension: remember)
 - The searcher recognizes a gap in his knowledge and understanding.
- II. Selection (understand)
 - The searcher identifies and selects a topic to be investigated, including the comparison of different aspects.
- III. Exploration (apply)
 - The searcher investigates information on the general topic or focuses on general viewpoints to extend his understanding.
- IV. Formulation (analyze)
 - The searcher forms a focused perspective on the topic, and a detailed analysis of the application being studied.
- V. Collection (evaluate)
 - The searcher interacts with the applicable retrieved information.
- VI. Presentation (create)
 - The searcher completes the information retrieval and uses the findings.

3.5 Reliability analysis

Reliability was verified using three independent approaches as presented in the method triangulation. The overall research methodology is verified by Sink's criteria (Sink 1985). This is presented in Table 5.

Table 5 Detailed descriptions of Sink's criteria (Talikka, Eskelinen 2013)

| CRITERION | BRIEF DESCRIPTION | APPLICATION OF CRITERION |
|------------------------|------------------------------------|---|
| Validity | Measures the intended object | The citation analysis is an objective and generally used method for evaluating used sources. ASIIN and ABET engineering learning outcomes come from outside the research and are internationally recognized. The ACRL Framework is also internationally used in reviewing IL knowledge. Miles & Huberman's method is a traditional, accepted method for validating interview results. Triangulation is used to evaluate if the results of all three independent observations give parallel results. |
| Reliability | Results are repeatable | The citation evaluation gives comparable parameters at the time of the research although they differ periodically. ASIIN and ABET engineering learning outcomes have been compared with each other and with previous versions. There are only minor differences. The Miles & Huberman's method is a traditional, accepted method for validating interview results. The interview answer classifications have been verified by cross-tabulation of colleagues' evaluations. |
| Accuracy and precision | Results cumulate around the object | The citation evaluation gives comparable parameters at the time of the research although they differ periodically. Other evaluations may give inaccurate results. Miles & Huberman is vulnerable but after quantification, it is accurate. |

| | | |
|---------------------------|---|---|
| Collective exhaustiveness | Forms a balanced overall analysis of the situation | Triangulation in Figure 8 produces a balanced image of the entirety. |
| Uniqueness | Only one instrument describes a certain characteristic | Citation analysis gives clear results. The questionnaire is designed to receive answers concerning limited topics. In using ASIIN and ABET engineering learning outcomes, the research focuses on mechanical engineering and sustainable science. |
| Comprehensibility | Results are understandable for all users | IL mindset development becomes visible through questionnaires and citation analyses. |
| Quantifiability | Results are presented or can be transformed into numeric values | Interviews and questionnaires are quantified – necessary results are quantifiable e.g. the analyzed open interviews. |
| Controllability | Can be tuned for different performance levels | There are more bibliometric parameters, which can be used to tune the results. The questionnaire can be developed to be even more precise and there can be repetitions of questions so that the kappa coefficients can be used. In cases when e.g. cross-tabulation is used the correlation coefficients can be defined to give stricter or looser interdependencies. |

| | | |
|---------------|--|---|
| Effectiveness | Benefits exceed inputs | The financial benefits of the new IL mindset are difficult to measure. However, the learning outcomes of brief integrated IL education can be observed. Moreover, there are measurable benefits in saving teachers working time when not all experts are needed to be present in class. |
| Relevancy | Value has an essential significance to decision making | Questionnaire answers and citation analyses show that when the brief integrated IL education is used, students' learning outcomes are parallel to those of ASIIN and ABET engineering learning outcome requirements. |
| Credibility | Decision makers trust in the value of the instrument | The purpose of developing the IL education was not only to improve students' IL skills but to gain also the ASIIN and ABET engineering learning outcomes. |
| Timing | Describes the current situation, real time results on hand | The citation analysis is bound to the time of the research. Results change with time, e.g. the accuracy of references. |
| Simplicity | Easy to learn and use | Characteristics to evaluate the significance and impact of references and evaluation based on ASIIN and ABET are single-valued. The qualitative analysis is more difficult and creating the evaluation criteria requires expertise. |

Method triangulation consists of focusing on characteristics to evaluate the significance and impact of references, qualitative analysis according to Miles and Huberman, and evaluation based on ASIIN and ACRL criteria. This is illustrated in Figure 6.

The third reliability factor is the cross-tabulation of classification analyses evaluation of the author and peers. Moreover, substance teachers performed blind evaluations of students' learning outcomes.

3.6 Ways to illustrate the results

The results are illustrated by using figures created by the Webropol survey tool and by Microsoft Excel. Tables are created from observation results.

4 Results

4.1 Scientific contribution

This study presents new scientific knowledge about the required changes in the IL education content due to the increasing complexity of future engineering problems to be solved. Prior studies report results of changes in students' searching skills (Baldwin, Gadd et al. 2010, Currie et al. 2010, Vollaro 2011, Talikka et al. 2014, Zabihian, Strife et al. 2015). However, this research presents new findings of the impact of brief IL education, which is integrated into substance education. How brief integrated IL education, which is integrated into higher education engineering studies, effects students' research problem formulation and the way they present respective information search questions has not been reported before. The results have been achieved by merging new IL content, which emphasizes a research perspective instead of traditional searching skills into engineering courses at LUT.

4.1.1 Impact of IL education on searching skills

To find out about the effect of IL education on students' search performance, their search plans were studied before and after IL education. In a pilot research (Talikka et al. 2014), students were asked before and after IL education, where and how they planned to search information for their assignment. The results were used to determine answer categories to be used in the full-scale study. There were two small groups, CM and RMaM, of students studied in the pilot research. Students were randomly divided into the research group, which attended IL education, and the comparison group, which did not attend it. The answers were grouped into two categories: those that dealt with the selected information sources and those that described the search terms. The questionnaire, which was used in this pilot study, is presented in Appendix 1.

When the planned and used information sources were studied in CM, some sources appeared to be more popular than others. These sources were Google Scholar,

Information retrieval portal (Nelli, at that time), Scopus, Library catalog, Internet (Google), and Science Direct. These sources were selected as the ones whose use was studied individually while the rest were classified as 'others'. The group 'others' consisted of very different kinds of sources: SpringerLink, EBSCO, Journal citation reports, information given by the professor, and peer students' help. The analysis showed, as presented in Figure 7, that the reliance on library online catalog decreased the most (from 17 to 0 per cent). Moreover, the planned use of open Internet sources also decreased from 8 to 0 per cent. However, after IL education students appeared to rely more on the Information retrieval portal (from 17 to 23 per cent), Scopus (from 17 to 23 per cent), and Science Direct (from 5 to 14 per cent).

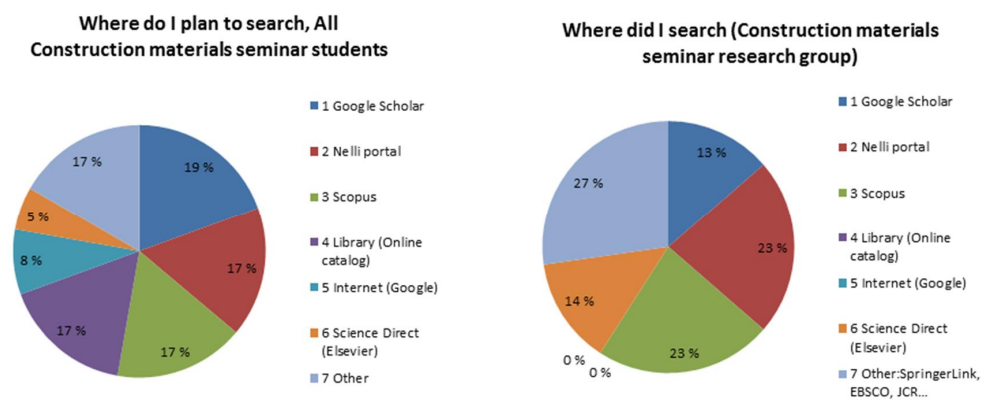


Figure 7 Change in planned information sources, CM (Talikka et al. 2014)

When the results were verified in an international group (RMaM), data source selections changed as presented in Figure 8.

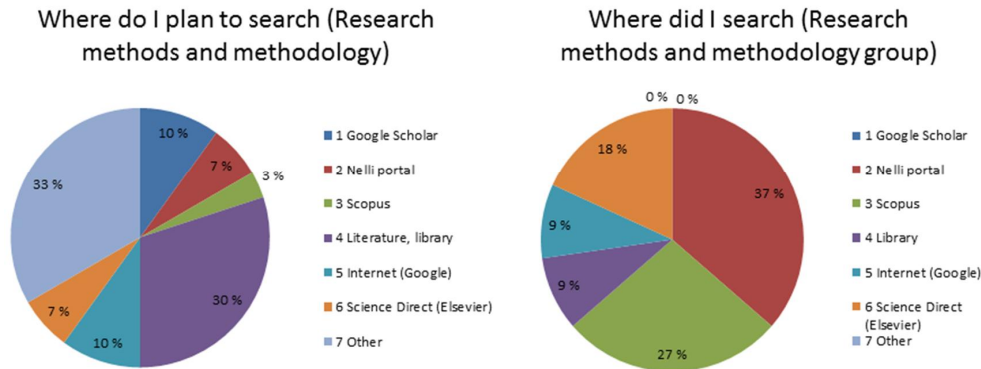


Figure 8 Changes in planned and used data sources, RMaM (Talikka et al. 2014)

All students planned first to use single search words or chains of words in their basic forms. In most answers, there were no apparent search strategies. Only a few students had a fuzzy idea of combining words. After the IL education students started truncating search words, using phrases i.e. words that form a concept together, and combining terms with Boolean operators to create logical search strategies. They used alternative search words and abbreviations and were able to create logical search queries by using parentheses in the search sentences. They also used the analyzing tool in the Scopus database and used the advanced search in databases where that feature was available. Moreover, Research methods and methodologies students, who had a joint lecture and hands-on training, also limited their searches by seeking the search terms to the title and keyword fields, by selecting a proper document type e.g. journal article, and by narrowing the search by viewpoint e.g. by adding limiting search words. Consequently, some of the Construction materials seminar students were able to evaluate the scientific status of the retrieved documents. The pilot study results are in Table 6.

Table 6 Changes in search word use, pilot study (Talikka et al. 2014)

| Before IL lecture | After IL lecture | After lecture and hands-on training | |
|--|--|--|------------|
| Basic form single words, keyword-type words. | Truncated words | Truncated words | |
| Word chains | Alternative search words (combined with OR) | Quotation marks indicating phrases. | |
| | Terms in full and their abbreviations (combined with OR) | | |
| No search strategy | Search strategies using Boolean operators. | Limiting the search term to title or keywords. | CM seminar |
| | | Limiting by document type. | RMaM |
| | | Narrowing the search by viewpoint. | All |
| Foggy idea of combining words | Boolean operators | Advanced use of Boolean operators. | |
| | Parentheses | | |
| | | Attention to impact factors | |
| | | Analyzing results, Scopus. | |
| | | Using advanced search. | |

The pilot research results were utilized when the categories for analyzing students' answers in other courses were created. Search strategies were studied in another Construction materials seminar group (Course A, survey questions in Appendix 2). The group consisted of 48 students. Surveys were sent to all attending students before IL education. Half of the class was then selected randomly to take part in IL education. They were the research group and to them another survey was sent after IL lecture and a third one after hands-on training. The first survey contained questions:

- Where and how do you plan to search information about your topic?
- What search words do you plan to use and how do you perform the search?

After IL education in class students answered questions:

- Where and how do you now plan to search information about your topic?
- What search words do you now plan to use and how do you perform the search?

After hands-on training students answered questions:

- Where did you search and where do you now plan to continue to search information about your topic?
- What search words did you use and how did you combine them? How do you plan to continue?

Before IL education students planned to use mainly library collections, the Internet, and the available search portal. After the IL session and hands-on training the interest to use the search portal was about equal of the situation before the session (from 23% to 29% and 27%). However, there were noticeable changes in planning to use the Library (from 32% to 14% and finally 4%) and Google Scholar (from 7% to 20% and 15%). Figure 9 shows the development in planned data source use. During hands-on training students learned to appreciate the Scopus database that was not very much valued before that. Its planned use increased from 5% to 31%.

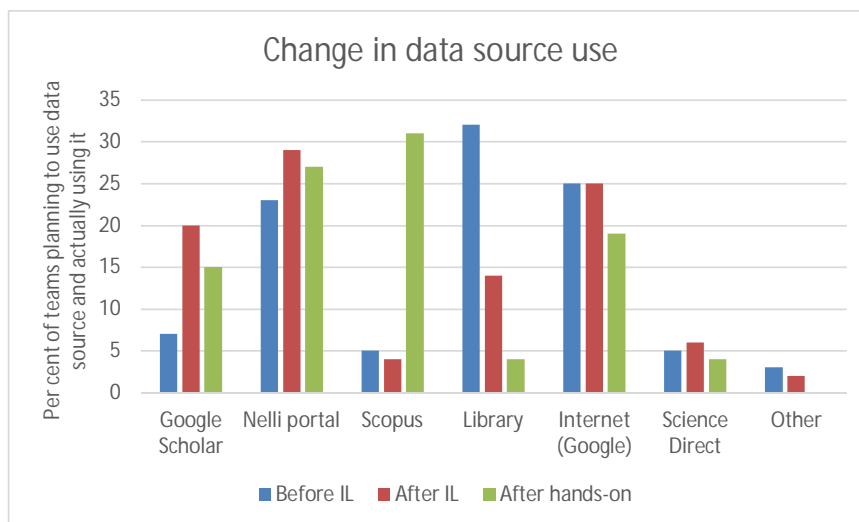


Figure 9 Planned data source use before and after IL education lesson and actual use of source after hands-on training, Course A.

The results were verified by comparing them with the results in another group (Course C, the questionnaire presented in Appendix 4) of the Mechanical engineering seminar (n=36). The trends were equal with the exception of Science Direct use but the percentages varied. In Figure 10 the changes in the studied groups are presented.

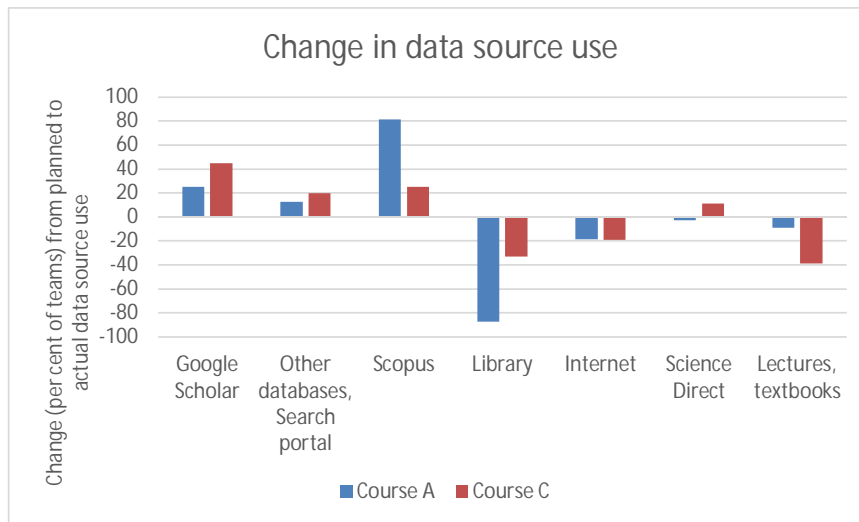


Figure 10 Increase/decrease of planned vs. actual data source use from the situation before IL education to after it, verification between Course A and Course C

Changes in planned search strategy on Course A (Figure 11) showed a decrease in using single words (from 63% to 10%) compared with the situation before IL education. Moreover, after IL education students' planned searches contained more Boolean operators (from 19% to 80%), truncated words (allowing searches to cover e.g. plurals and different endings) (from 3% to 53%), phrases (from 3% to 30%) and limiting the search in appropriate ways (from 3% to 26%). In some cases, the percentage of the planned strategies changes unexpectedly after the lecture and after the hands-on training.

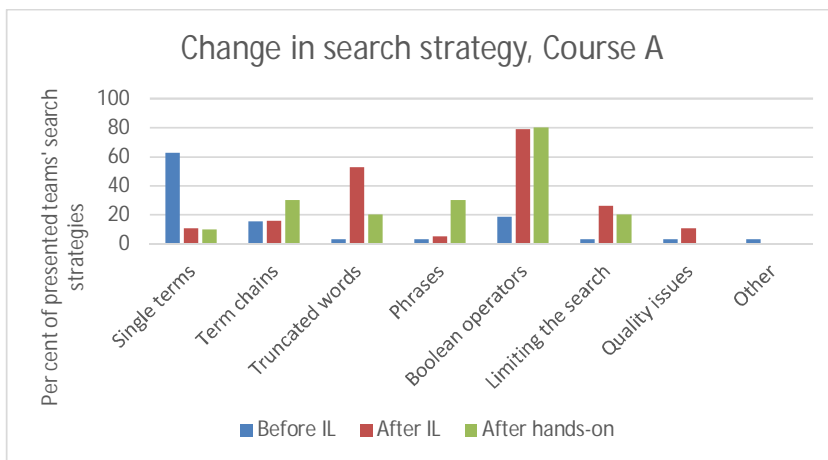


Figure 11 Planned teams' search strategies before and after IL education lessons and actual strategies after hands-on training, Course A.

The results were verified by studying the results of Course B. Except of term chains and limiting the search the trends are parallel as presented in Figure 12.

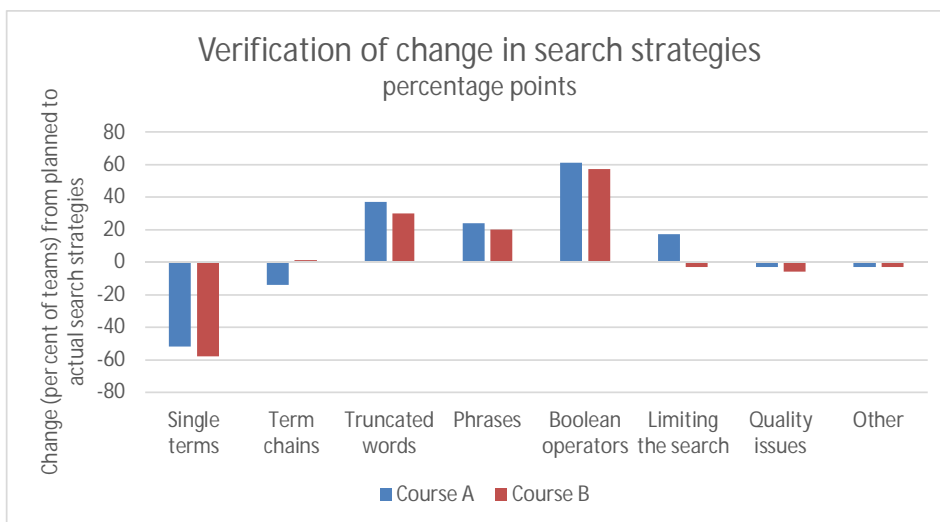


Figure 12 Increase/decrease of planned vs. actual search strategies from the situation before IL education to after it, verification between Course A and Course B.

4.1.2 Impact of IL education on research problem formulation

Interaction between understanding the research problem and using the searcher's information literacy qualifications is distinctive in solving the problem. Rieh et.al. (Rieh, Collins-Thompson et al. 2016) have studied interaction between information seeking and learning. They conclude that the association of searching and learning is complex and unclear. They see, however, a potential of search interaction data to support and assess search-related learning. According to their findings and those of Du and Evans (Du, Evans 2011), most of the interaction studied so far is between the research task and search behavior. Moreover, Vakkari argues that there are two basic notions of information searching. The bibliographic paradigm means searching and evaluating the result while the constructive notion relates to learning and includes using the information in the found documents (Vakkari 2016). These views approach the question of the interaction between information searching and research problem formulation. However, they do not fully answer the question although it can be presumed that learning, in some cases, may revert to discussing the research problem.

The question about the interaction between IL education and students' research problem formulation was studied in three parts: the pilot study focused on determining if there was any kind of effect of IL education on research problem formulation. The second part concerned the effects on Course A students who described their research problem before IL education and their research problem descriptions were studied in the final papers. In the third part, students on Course C presented their research problem formulations at three stages: before IL education, after IL education and after the course (Appendix 4).

In the pilot study, students were asked to determine their research problems before and after IL education. The analysis of the answers showed clear differences between the research group and the comparison group. At first students did not give any real definition of the research problems but after IL education when the final papers were examined, the research group teams either presented it clearly or at least it could be found in the paper

while in the comparison group papers no noticeable definition of the research problem could be found. The results are presented in Table 7.

Table 7 Analysis of research problem descriptions in the pilot study (Talikka et al. 2014)

| Before IL education, all teams, pilot | In the final papers, pilot | |
|---|---|--|
| | Research group (3 teams) | Comparison group (1 team) |
| Lists of concepts | Two teams presented a clear determination of the research problem | No noticeable definition of the research problem or research questions |
| Single words in basic form | | |
| One team presented a why-question but no research problem | One team presented their research problem less clearly but it could be found in the abstract of the paper | |
| Students did not understand the question about research problem. They answered by giving the title of the paper | | |

This study was repeated in two full scale studies. In the first one (Course A, Appendix 2) the research problem descriptions were collected before IL education from all students. Then five out of nine teams were selected to form the research group that attended IL education, which consisted of two 90-minute sessions: one lecture and one hands-on training session. The remaining four teams worked on their seminar papers without IL instruction. After the course, the research problem descriptions were analyzed in the final papers. The substance teacher did a blind analysis of the papers i.e. without knowing which students attended IL education. (Talikka et al. 2015)

Clear progress could be seen in the research problem definitions as presented in Table 8. Before IL education, 10 per cent of the students presented a clear research problem. Forty two per cent presented the title of the paper as the research problem and 29 per cent formulated their research problem as a task. The rest of the students had either no (16%) or just a fuzzy idea (3%) of what the research problem means. (Talikka et al. 2015)

Table 8 Research problem formulation before IL education, Course A (Talikka et al. 2015)

| Before IL education, Course A, all groups | |
|---|------------------------|
| Classification of research problem | Percentage of students |
| No idea what the research problem means | 16 |
| Title of the paper | 42 |
| Presented as a task | 29 |
| Fuzzy idea of the research problem | 3 |
| Clear research problem | 10 |

In the finished seminar papers four out of five of the research group teams presented either a clearly (2) or reasonably described (2) research problems and in one team's paper the research problem was not clear. In the comparison group, one team described their research problem clearly and three descriptions were not clear. These results are presented in Table 9.

Table 9 Research problem descriptions after IL education, Course A, faculty teacher's evaluation (Talikka et al. 2015)

| Seminar paper, Course A, faculty teacher's evaluation | | | |
|---|----------------------|----------------------------|---------------------------------|
| Substance teacher's comments | | Research group, 5 teams | Comparison group, 4 teams |
| Research problem and goal description | described clearly | 2 | 1 |
| | described reasonably | 2 | 0 |
| | not clear | 1 | 3 |

In case of Course C (Appendix 4), students answered to 'What is/are your research question/s?' before and after IL education. Based on the knowledge hierarchy of Ackoff (1989) and the sustainability maturity curve by Fava (Fava 2014, Burgess 2014), a four-part classification was generated to categorize the depth of students' research questions (Talikka et al. 2018). The categories were:

- I. Questions concerning recognizing the limitations in the use of materials (may concern legislation, technical standards etc.)
- II. Questions concerning the sustainability of chosen materials
- III. Questions focusing on the sustainability of the applicable material options and their benefits
- IV. Questions related to the most sustainable way to fulfill the needs of the application

Changes in the formulation of the students' research questions were studied and the results are presented in Figure 13. Students' definitions of their research questions were categorized in four groups based on the classification created for this research.

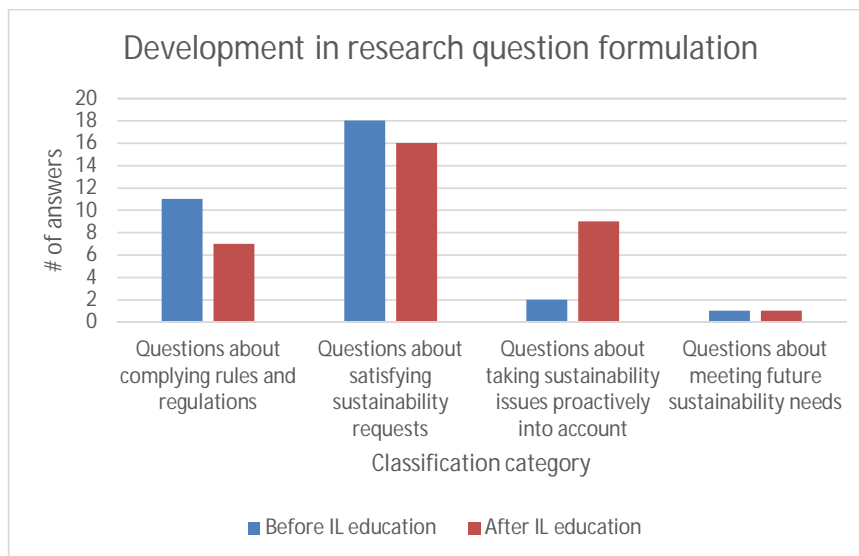


Figure 13 Development in research question formulation, Course C (Talikka et al. 2018)

From the figure, it can be seen that before the IL education students' research questions addressed mainly recognizing the limitations of the use of materials in the application (34 per cent) and the sustainability of the chosen materials in the particular environment (56 per cent). After the IL education, their research questions still focused on sustainability issues of applicable materials in the given environment (48 per cent) but the proportion of research questions concerning the sustainability of the applicable material options and the benefits of the materials had increased from 6 per cent before IL education to 27 per cent after it. However, according to this classification, which was based on the sustainability maturity curve, only one of the mechanical engineering students' research questions – both before and after IL education – could be categorized to seek an answer to 'how to meet future sustainability needs'.

In the survey, students answered a question about whether their research problem had become clearer during the IL education process; 61 per cent agreed that understanding of the research problem had improved. Students commented for example:

'Yes it became [clearer] because we get more information on our subject'

'Yes, before research problem it was too general. After this we came more close and deep to the topic.'

'Yes, at the start we consider to evaluate the whole assembly of tidal turbine but we saw that was too complicated so we narrowed down to only the blade assembly'

'During the process of development, it was possible to add more details and viewpoints to our research problems and it got more clear in the end'

Students who thought that their research problem was not clearer after the IL education (39 per cent) commented, e.g.:

'No, I don't think so. It was exactly what we wanted in the beginning of this seminar work.'

'For the most part it remained the same'

'Well, our research problem was quite precise and focused from the beginning.'

'We had problems with our research problem.'

4.1.3 Impact of IL education on information search questions

The goal of information retrieval and whether or not it is worthwhile to start the searching process depends on the searcher's basic knowledge of the topic. The research question and the researcher's expertise define both the content and the extent of the information search and the questions that need to be answered via the retrieved information. Bruce W. Tuckman (1994) discusses the purpose of literature search. According to the author, relevant literature can be used to discover the researched scope of interest, find out about earlier studies of the topic and the gaps in previous knowledge, gaining perspective of the topic, determining meanings and relationships of concepts, studying the context of the problem, and demonstrating the importance of the problem. Thus, literature search can be

used as a tool to find a solution to different parts of the research problem and perhaps the search result can even help in clarifying the research problem.

Evaluation of the development of students' information search questions was done by using the six-point classification by Vakkari (2000) and Kuhlthau (1993, 129-143).

In evaluating students' understanding of the information search questions, Course C student teams were studied. They answered the question 'What is/are your information search question/s?' at three stages: before IL education, after IL education, and after the entire course (Appendix 4).

Their answers were evaluated using the previously presented categories. Analysis of students' answers is illustrated in Figure 14.

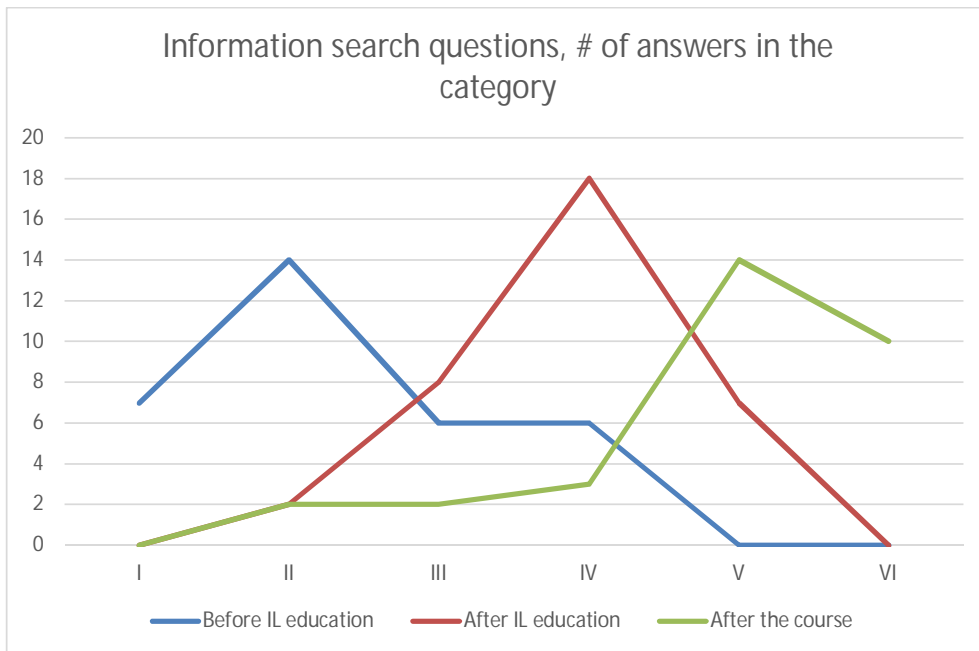


Figure 14 Due to IL education students' information search questions develop from finding facts and comparison information to detailed, application based information. After the course, students express information needs for interacting with the information and creating new knowledge (Talikka et al. 2018)

There was a clear change from searching for fact and comparison information before IL education to moving, after IL education, towards more detailed information search where the interest was in analyzing the properties of selected materials and their use in the application. After IL education, a significantly greater number of students presented information search questions that focused on evaluating the retrieved information and how it could be used in connection with the previously acquired knowledge. Moreover, after the experience of writing a paper, their information search questions contained ideas of interacting with the retrieved information and using it in their research to create new knowledge.

The results were verified by three information specialists who are the author's colleagues. According to the cross-tabulation, the differences with Colleague 1 and Colleague 3 are

not statistically significant while the differences with Colleague 2 are statistically significant. The verification is presented in Table 10.

Table 10 Verification of information search question evaluations

| par value, limit value 0.05 | | | | |
|-----------------------------|----|-------------|-------------|-------------|
| Verification of evaluations | | Colleague 1 | Colleague 2 | Colleague 3 |
| Before education | IL | 0.05735 | 0.00760 | 0.96007 |
| After education | IL | 0.10105 | 0.01398 | 0.86143 |

4.1.4 Other findings

Citation analysis

A citation analysis was made on the Construction materials seminar papers to evaluate the status of the information sources used by this pilot course. According to the analysis, the research group used nearly twice as much academic journal articles (58%) than the comparison group (29%) as illustrated in Figure 15. (Talikka et al. 2014)

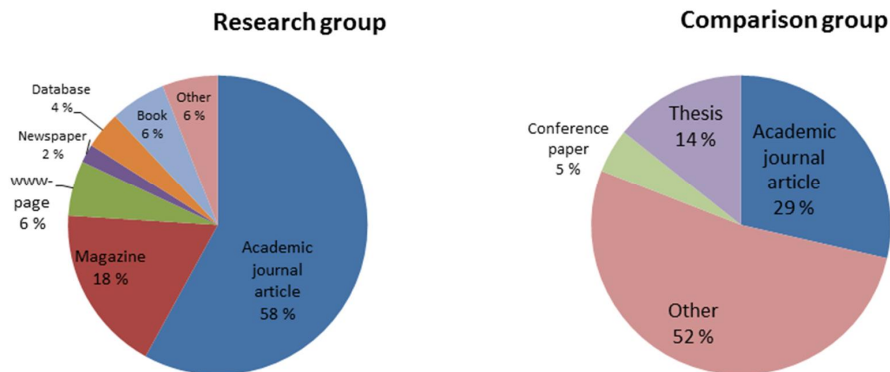


Figure 15 Citation analysis of used sources, Construction materials seminar, pilot study (Talikka et al. 2014)

The citations were also observed from the reference lists of Course C papers. All students on that course attended IL education. Randomly selected three teams out of eight were analyzed. The results, which are illustrated in Figure 16 show that 52 per cent of the used references were academic journal articles, 16 per cent were conference proceedings, 10 per cent web pages, and 18 per cent books. The distributions of the use of academic journals and web pages were parallel to that of the pilot study. However, Course C students used more conference proceedings and books than were used in the pilot study. The groups 'Thesis' and 'Other' were minor.

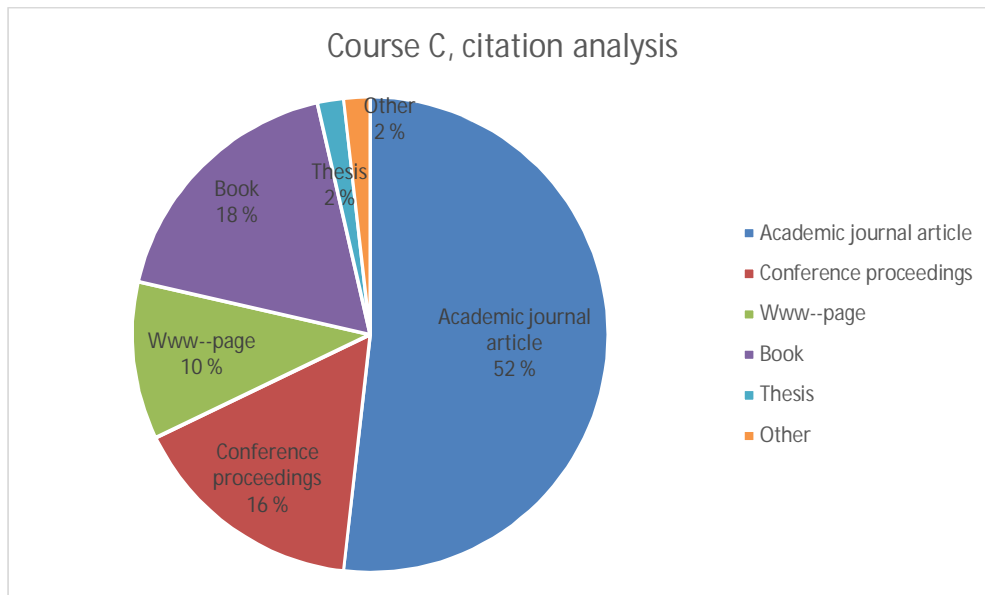


Figure 16 Citation analysis of used sources, Course C

When the publication dates of the references were studied, it was noticed that in the pilot study the research group used newer sources than the comparison group as presented in Figure 17. On average, the comparison group cited more sources than the research group. The references were mostly written in English but the comparison group had also used many Finnish sources.

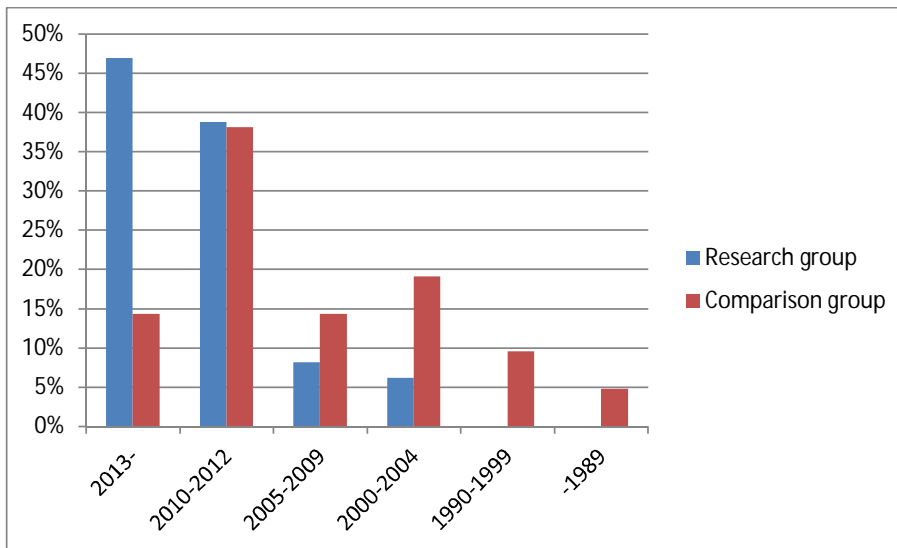


Figure 17 Publication years of used sources, Construction materials seminar, pilot study (Talikka et al. 2014)

The publication year distribution in Course C papers is presented in Figure 18. On Course C, all students attended IL education. The figure shows that also on this course the cited references were quite recently published. However, the share of documents published during the two previous years before the course was smaller than that in case of Course B.

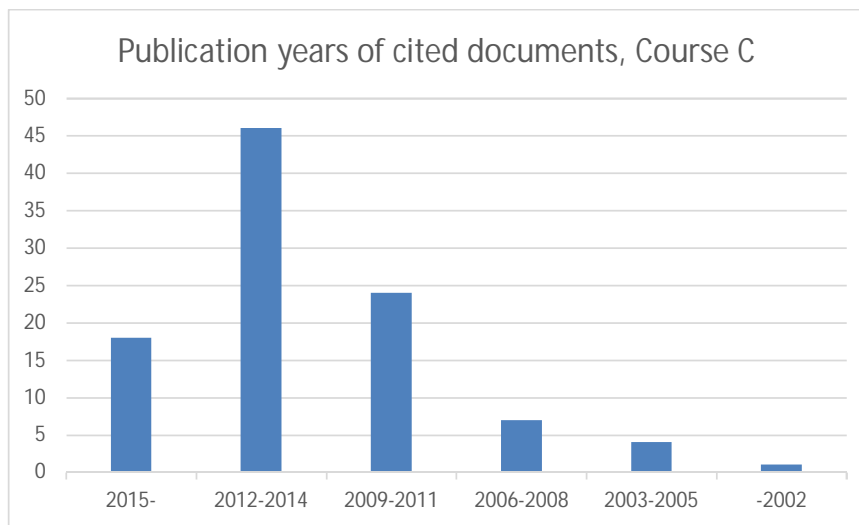


Figure 18 Publication years of used sources, Course C

Differences in the presentation of the paper

The substance teacher examined the Course A final papers and the evaluations are shown in Table 11. The IL educated students handled the cited sources in a more mature way which was seen in how they discussed the matter, including the reasons and consequences of appearing phenomena, via the references while the comparison group presented just the existing facts without interpretation or their own thoughts with the aim to get as much text as possible in their work even if it was copy-pasting to meet the text amount requirements.

According to the substance teacher's evaluation, there was also a difference in developing the topic. The IL educated students also had a wider view of the matter including supporting and opposing viewpoints and background information while the comparison group mainly searched references that supported their own thoughts.

Table 11 Substance teacher's evaluation of students' way of presenting their paper, Course A (Talikka et al. 2014)

| IL educated students | Students with no IL education |
|---|---|
| present a dialogue with the found references | copy-paste text, nearly plagiarism, bulk text to meet the amount requirements |
| formulate and analyze the research problem | |
| discuss reasons and consequences of different phenomena | present just the existing facts without any interpretation or own thoughts |
| describe the development of the topic in a logical timeline / present the results either in a comparison or SWOT analysis table | |
| are aware that some references support their results but some might present even opposite viewpoints | mostly look for references which best support their own ideas and thoughts |
| use references to form background, present cases, verify conclusions | |

To study students' research behavior, the final papers of Course A and Course B were observed. Substance teachers listed important words that relate to the topic of the course. The appearance of topic-related words in assignment papers was calculated by using text mining. The texts and reference lists were observed separately.

On Course A, eight topic-related words were mapped in the papers. According to the observations, students concentrated on classical construction materials (metallic materials, polymers, ceramics, composites) but adaptive and nanomaterials were mentioned less. In information searching, same grouping was seen in the way students used search words (data collected from questionnaire, which is presented in Appendix 2). Differences in word counts between research and comparison groups were apparent.

On Course B, the number of topic-related words was 16. The same finding was discovered on this course as on the other one: numbers of words representing the observed topics were higher in the research groups' papers compared with those of the comparison groups' papers. However, differences between research and comparison groups were not equally notable as they were on Course A. The results are presented Table 12.

Table 12 Average number of observed words representing substance topics (Talikka et al. 2014)

| Average number of observed words representing substance topics | | |
|--|----------------|------------------|
| | Research group | Comparison group |
| Course A, text | 189.8 | 119.8 |
| Course B, text | 66.1 | 58.5 |
| Course A, references | 11.4 | 2.8 |
| Course B, references | 9.1 | 6.9 |

Findings about final grades

Final grades of Course A and Course B were also viewed. When the final grades on Course A were compared, the research group students' average was 4.1 out of 5 while the comparison group's average was 3.2. On Course C, which was also a mechanical engineering seminar course, all students attended IL education. On that course, the average final grade was 4 out of 5.

On Course B, the substance teacher evaluated the seminar papers and the use of references and gave the final grade. Students who participated in IL education scored better in all the evaluations. The biggest differences were in the use of references where the IL educated students' average score was 4.23/5 while the non-IL-educated scored an average

of 3.49 and the whole class' average score was 3.65. On this course, there were only minor differences in the final grades. The evaluation is presented in Table 13.

Table 13 Evaluation of Course B seminar paper scores (Talikka et al. 2014)

| Course B scores of seminar papers | Average, all 106 students | Average, 22 students who participated in IL education | Average, 84 students who did not participate in IL education |
|---|---------------------------|---|--|
| Total score of the assignment, max, 30 points | 25.87 | 26.77 | 25.64 |
| Score of the use of references in the assignment, max, 5 points | 3.65 | 4.23 | 3.49 |
| Final grade of the course (max 5) | 3.04 | 3.14 | 3.01 |

On Course C, the results of the categorization of the research problem descriptions and information search questions were analyzed by cross-tabulation with the final grades given by the substance teacher. Additionally, the research problem descriptions and information search questions were studied by cross-tabulation to clarify possible interdependence.

The interdependences between the final grade and understanding of the research problem or ability to present appropriate information search questions were analyzed using cross-tabulation. The scale of passing grades on the course ranged from 1 (pass) to 5 (excellent). The grades awarded ranged from 2 to 5 with the grade average being 4.0.

The correlation between the final grade and understanding of the research problem appeared to be non-significant ($p=0.703$). Equally, there seemed to be no significant correlation between the information search questions and the final grade. However,

according to the results from the cross-tabulation of the classifications of the research problem description and information search questions, there was a positive correlation between these two factors ($p=0.037$). The limit value of p was 0.05.

4.2 Concrete applications

As a result of integrating IL education into substance education, interaction between IL and substance education enhances students' IL mindset development.

Four main phenomena are discussed:

- a) How an effective formulation of the search query could be derived from a set of technical parameters?
- b) How focused IL education could be integrated to support substance teaching in mechanical engineering?
- c) In what ways successful IL education could deepen the formulation of research problem in the field of mechanical engineering?
- d) How the results of integrating IL and substance education can be generalized to cover different branches on engineering, e.g. mechanical engineering and environmental technology?

4.2.1 How an effective formulation of the search query could be derived from a set of technical parameters?

An illustrated example can be found in the materials selection process of ceramics. The material properties of any ceramics can be tuned by adjusting grain size, porosity, purity, alloying, direction of compression, sintering, and of course by selecting the main powder component. If wisely used, IL education could give the reasonable advice how to utilize Boolean operators (OR/AND/NOT functions) and the truncation character. The substance teacher can guide the students to select proper combinations of these properties. The role of the IL instructor is to teach the students how to do it. This phenomenon is illustrated in Figure 19, which is derived by Professor Harri Eskelinen from a figure presented by Eskelinen and Karsikas (Eskelinen, Karsikas 2013).

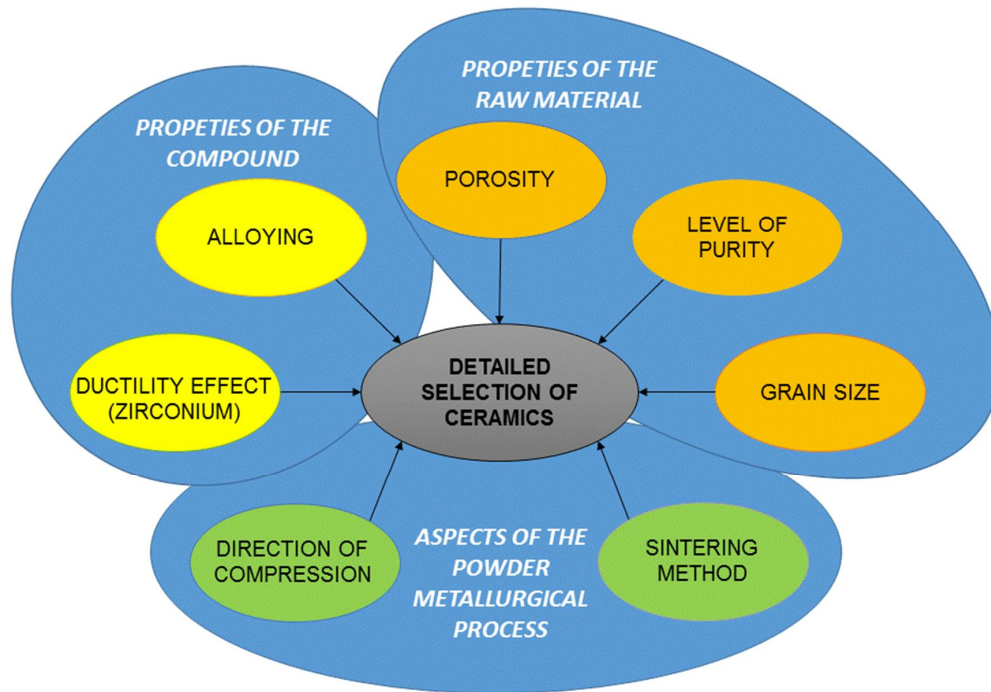


Figure 19 Aspects to consider in selecting ceramics (Eskelinen, Karsikas 2013, p. 217)

4.2.2 How focused IL education could be integrated to support substance teaching in mechanical engineering?

During substance teaching, summarized data tables are usually presented to highlight e.g. which ceramic materials are the most suitable for specific applications and what the main material property to justify the use is. These types of summary tables open a new door for IL education: three different paths can be utilized to deepen the general data given in a summary table. IL education could advise the student to find additional information about a) the ceramic material itself, b) the application or c) the key material property. By following these three information paths, the student will be able to add knowledge in this otherwise simplified data table. This kind of work is illustrated in Table 14.

Table 14. Justification of ceramic applications and examples of questions by which the IL teacher can help the student in material selection

| Ceramics | The most important property for industrial applications | Some examples of questions which the IL teacher can ask to help the student in material selection |
|--------------------|--|--|
| ALUMINIUM OXIDES | Cost-effectiveness compared to other ceramics with good chemical resistance. | Are there any other properties of aluminium oxides that should be taken into account in this application? What does 'good chemical resistance' mean? |
| ALUMINIUM NITRIDES | Excellent thermal conductor but at the same time excellent electric insulator. | Considering the application, are any of the properties of aluminium nitrides disadvantageous? In what kind of applications could materials that are at the same time excellent thermal conductors and electric insulators be used? |
| SILICON CARBIDES | Good heat resistance. | Are there any similar applications in which silicon carbides have been used? Can you find a connection? There are different silicon carbides. Could you find more specific search words for them? |

| | | |
|---|--|--|
| SILICON NITRIDES | Good heat resistance combined with excellent resistance against heat shocks. | Do other properties of silicon nitrides meet the requirements in this application? There are different silicon nitrides. Could you find more specific search words for them? |
| Si-Al-O-N (one type of silicon nitride) | Mechanical properties close to Silicon nitride combined with chemical resistance close to properties of Aluminium oxide. | Could the chosen materials be compared with some others which have the same kind of properties, considering e.g. price or usability? |
| ZIRCONIUM OXIDE | Could be utilized to improve the toughness / ductility of other ceramic materials. Use in oxygen sensors. | Are there any trade names for zirconium oxide? Trade names could be used as search words. |
| BORON CARBIDE | Extremely hard (place 4. in the list of constructional materials) | What other property requirements are there but hardness in this application? Does boron carbide meet them? |
| BORON NITRIDE | Extremely hard (place 3. in the list of constructional materials) | Are there any environmental issues that need to be taken into account? |

One detailed example of the following deals with Boron carbides and nitrides, which are used in many military applications and where commercial ceramic materials are used. Of course, the previously mentioned three paths could be followed, because the main reason

for using Boron is the hardness of the compounds. A competent IL educator could see this issue also in another way. Because it is relatively difficult to find detailed information on military applications, the IL teacher could advise the student to find appropriate databases to support the information search. Material properties could be found in scientific databases, the aspects of military applications are described in military standards, and information about the commercial products might be found either in scientific or business oriented databases or even in web sites. This is illustrated in Figure 20.

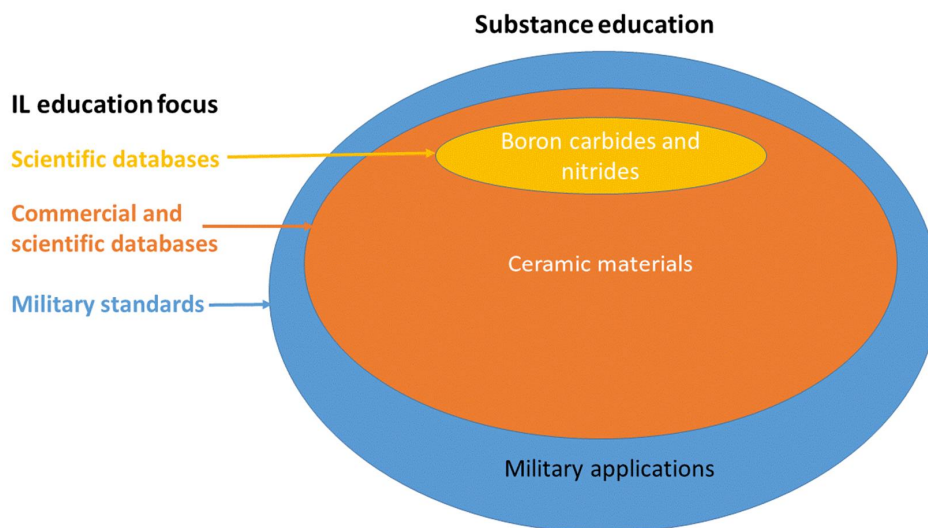


Figure 20 Supporting information sources in a challenging search situation

4.2.3 In what ways could successful IL education deepen the formulation of research problem in the field of mechanical engineering?

Successful IL education can support formulating the research problem. Many different aspects should be discussed e.g. under the systematic material selection process of ceramic materials: the research problem includes at least some aspects dealing with powder properties, ceramic grades, and sintering methods. On the other hand, the

systematic material selection process deals with four main progression steps: establishing functional requirements, environmental requirements, manufacturability, and costs. During the formulation of the search query, students are advised to combine, integrate, compare or select different number of aspects to be added to their search query. This is the stage where they are able to construct the research problem and the search query concurrently. Moreover, careful thinking of possible search words affects interactively: the literature search becomes more efficient and the core of the research problem becomes more visible. In some cases, it happens that the search query leads to limited and reasonable amount of relevant references that could be regarded as a sign of the real focus of the research problem. If the number of relevant references is huge, the IL teacher could advise students to find either trends or other time-depending changes among the references, which might clarify the research problem. These kind of analysis tools are available e.g. in Scopus. This chain of making conclusions is presented in Figure 21.

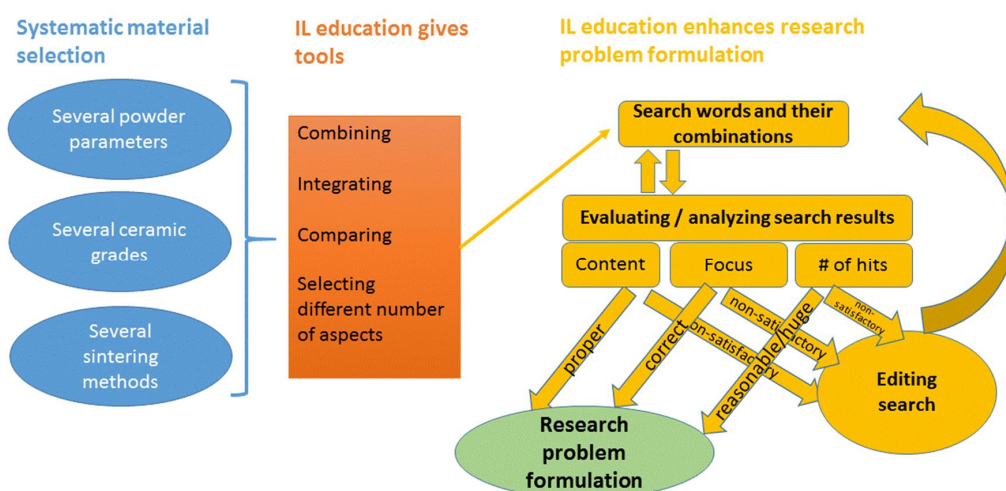


Figure 21 How IL education supports research problem formulation.

4.2.4 How the results of integrating IL and substance education can be generalized to cover different branches on engineering, e.g. mechanical and sustainability engineering?

In detailed material selection problems, the supporting literature search could start from finding the key parameters, their combinations, numerical values etc. that all could be regarded as detailed aspects. When the research problem is connected with sustainability, life cycle assessment or other viewpoints that form an entity are discussed. In that case, the direction of literature search is from general to towards details. Moreover, information from different types of databases and other sources is needed to solve the problem. In many cases, the analysis is connected with either laws or directives. The IL teacher should be able to follow the chain of continuously changing lists of standards, laws, directives and other documents and guide students to do the same.

An important viewpoint, which the IL teacher should be able to understand and utilize, is that both the literature search process and the suggested databases and other sources will change if the research problem turns to a general one instead of dealing with detailed material selection tasks. Alternatively, a material selection task can also be connected with sustainability and life cycle issues depending on the selected framework and viewpoint. These situations are illustrated in Figure 22.

From Figure 22 it can also be concluded that many mechanical engineering problems include aspects from sustainability engineering. The search area of relevant references includes these two viewpoints. Effective IL education is capable of integrating two branches of engineering to study the problem together. It is relevant to think what might be e.g. the energy consumption aspects of powder manufacturing in ceramics industry or how environmental aspects should be taken into account during the life cycle of a ceramic product. In this kind of case, IL education can integrate both the technical and the sustainability aspects together. Moreover, it is notable that in teaching IL in interdisciplinary contexts Bloom's taxonomy knowledge and cognitive levels (Anderson,

Krathwohl 2001) are worth utilizing. The more complex and in-depth the problem, the more various levels of the taxonomy should be applied.

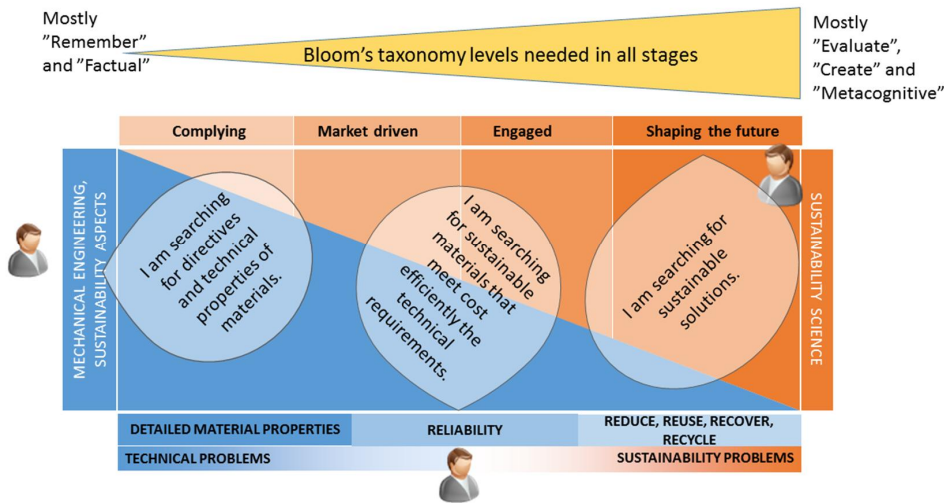


Figure 22 Integrating two branches of engineering in studying the problem.

4.3 Generalized results

The impact of brief integrated IL education on students' searching skills, on their research problem formulation, and on their information search questions was studied. Based on the measured results and observations, the students' IL mindset change was evaluated.

Students' searching skills, their use of references, and the contents of finished seminar papers were first studied on Courses A and B by comparing the results of those students who attended the IL education with the comparison group results. Changes in students' research question formulation and information search questions were then evaluated on Course C by using classifications, which were created for that purpose. On that course, the whole student population formed a research group. The developed student research question classification was based on Ackoff's (1989) knowledge hierarchy combined with categories in the sustainability maturity curve by Fava (Fava 2014, Burgess 2014).

The change in formulation of the information search questions was studied by using a six-level classification which was also generated for this research and which based on Kuhlthau's and Vakkari's model of six different stages in information searching (Kuhlthau 1993, Vakkari 2000) and Bloom's cognitive process taxonomy (Anderson, Krathwohl 2001).

Based on the presented evaluations it was obvious that as a result of brief integrated IL education a change in students' IL mindset could be verified. Students' information searching skills improved and they applied more efficient search tools than before IL education and used higher quality information sources in a more scientific manner compared with the comparison group. The profundity of the research questions also improved during IL education, according to the applied analysis. The students showed both deepened understanding of their research problem and a more distinct focus on sustainability. Moreover, the information search questions developed strongly from fact-dependent to focusing on creating new knowledge. According to the students' own evaluation, their search results became more precise and useful. There was a significant correlation between understanding the research problem and information searching. However, the final grades on the studied course did not correlate with either activity.

5 Discussion

5.1 Comparison and connection with former research

To get a view of the research on information literacy in higher education within the field of engineering a search was performed in the Scopus database. Although Scopus does not include all of the potential documents a comprehensive selection of journals and conferences that publish articles on information literacy are indexed in it. Therefore, it gives a comparable and global view of the topic.

On July 17th, 2017, the number of retrieved documents answering the search “information literacy” and (“higher education” or universit*) in Scopus was 2100. The set was analyzed by using the Scopus analyzing tool, which shows e.g. the distribution of printing year and subject area. According to the analysis, the number of publications has increased yearly as presented in Figure 23. The majority of the documents represent social sciences (81.1 per cent) while engineering was classified as the topic in 5.2 per cent of the publications as illustrated in Figure 24.

Documents by year

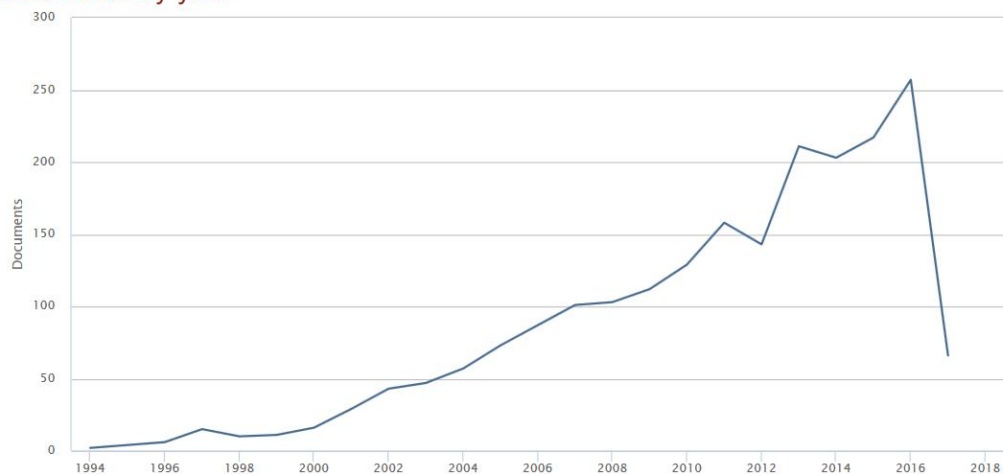


Figure 23 Distribution of documents about IL in higher education according to the Scopus database and its analyzing tool

Documents by subject area

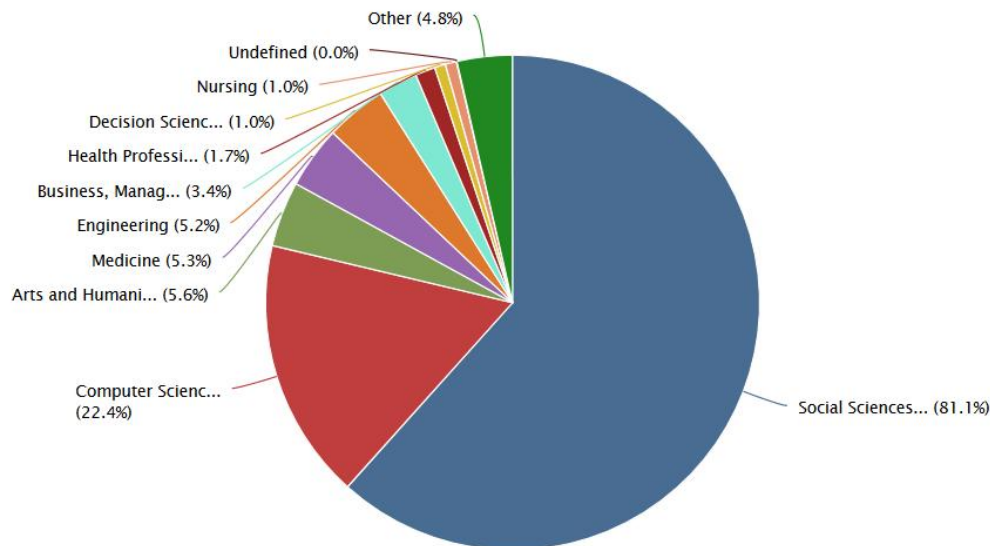


Figure 24 Subject areas within the search set of documents dealing with information literacy research in connection with higher education

Research on IL in higher education institutions appears to relate to disciplines like social sciences and computer science. However, it should be noticed that information literacy in general is considered a part of social sciences. Due to a low number of research on IL in connection with engineering, this research is noteworthy.

In order to find out about research on brief integrated IL education in the engineering higher education, a search for ((“information literacy” and (“higher education” or universit*) and (brief or short) and (educat* or teach* or instruct*) and (integrat* or embed*)) retrieved only two references from Scopus. The older one was published in 1994 (Connell, Franklin 1994) and was not useful because the words *brief* or *short* were not used in the context of the length of the IL education. The newer article was published in 2012 by Maitaouthong et al. (2012) and it addressed relevant topics. The exactly same kind of search could not be performed in Google Scholar to verify the result. However, while using the applicable Google Scholar tools ("higher education" AND university

AND brief AND education AND integrated AND title: "information literacy") the result showed that within 27 retrieved documents there were multiple duplicates and only one reference (Agee 2007) was relevant to add value to this research. Therefore, we can say that the topic of this research namely the influence of brief integrated IL education on higher education engineering student IL mindset and research performance is not studied widely if at all.

Based on the literature search results, the effects of IL education are mostly studied from the viewpoint of students' ability to find and combine search words and select suitable data sources for searching. However, focusing on how students understand their research problem and how they formulate their information search questions have not been discussed in literature.

Searching skills improve as a result of IL education. There is plenty of research on the development of students' searching behavior and skills (Larkin, Pines 2005, Julien, Barker 2009, Baldwin et al. 2010, Currie et al. 2010, Bronstein 2015). This is also evident according to this study. The notable aspect here is that the improvement is achieved after brief IL education, which is not substantially dealt with in literature.

5.2 Objectivity

The objectivity of this research is based on the scientifically accepted research methods. Text mining gives quantitative results, which are unambiguous. The citation analyses are standardized and thus objective. The qualitative evaluations are based on classifications, which are created by using existing scientific literature, and quantified by using the Miles & Huberman method that is a traditional, accepted method for validating interview results (Miles, Huberman 1994). Peer information specialists and substance teachers verified the evaluations. The qualitative results of the searching skills survey were retrieved directly from the Webropol survey tool. They were quantified by using the Miles & Huberman method. Substance teachers evaluated students' papers without knowing which students were in the research group and which in the comparison group.

5.3 Reliability and validity

The citation analysis is an objective and generally used method to evaluate used sources. It gives comparable parameters at the time of the research. Timeliness of the citations differs periodically but this can be taken into account by setting the scale according to the year when the observed document was written.

ASIIN (2011) and ABET (O'Hern 2012) engineering learning outcomes come from outside the research and are internationally recognized. The quality assurance criteria have been compared with each other and with previous versions. There are only minor differences between different years' versions.

The Miles & Huberman method is a traditional, accepted method to analyze and validate interview results. The interview answer classifications, which can be affected by the author's own views, have been verified by the cross-tabulation of colleagues' evaluations.

Triangulation is used to evaluate the parallelism of all three independent observation results.

5.4 Assessment of the results and sensitivity analysis

This study on the effects of brief integrated IL education on engineering students' research performance was performed during a three-year period on five different courses (CM, RMaM, Courses A, B, and C). In all of the studied cases, students' searching skills improved notably after IL education as presented in Chapter 4.1.1. Therefore, we can argue that brief integrated IL education has a positive effect on students searching skills.

Evaluation of research question formulation was done during a three-year period on four different courses (CM, RMaM, Courses A and C). All results showed that brief integrated IL education enhances students' research problem formulation. Research questions were evaluated by the substance teacher on courses CM, RMaM, and Course A. On Course C the author of this work evaluated the research questions. However, the substance teacher checked the evaluations.

Evaluation of information search questions was done on Course C. There was a clear change from searching fact and comparison information before IL education towards more detailed information search where the interest was in analyzing the properties of selected materials and their use in the application. After IL education, information search questions focused more on the quality of the retrieved information and how it could be used in connection with the previously acquired knowledge. After the course, students reported that towards the end of their writing process their information search questions contained ideas of interacting with the retrieved information and using it in their research to create new knowledge. The author of this study evaluated the information search questions. Three peer evaluators verified the evaluations. On the grounds of the cross-tabulation, the evaluations were parallel and with the exception of one peer evaluator, there were no significant differences in them.

Method triangulation was used to verify the results. The results were viewed from three viewpoints: a) characteristics to evaluate the significance and impact of references, b) qualitative analysis according to Miles and Huberman, and c) evaluation based on ASIIN, ABET, and ACRL criteria.

The significance and impact of references were viewed by conducting citation analyses of the used references and by substance teachers' evaluations of the validity of the referred information sources. The citation analyses showed that students who attended IL education used more scientific publications than the comparison group. Moreover, the source publications used by the research group were newer than those used by the comparison group. However, students in the research group used somewhat fewer information sources than their peers in the comparison group. This can mean that research group students were perhaps more efficient in their search processes. Analyses of the papers also showed that the research group students discussed their research problem via the source publications while many of the other students only referred to them and tried to create bulk text in a way that was close to plagiarism.

The qualitative analysis according to Miles and Huberman showed that students who had attended IL education created improved search queries after the IL education. Moreover, their research problem formulation and information search questions showed that they had much deeper understanding of their research problem and they asked information search questions, which helped them to find literature to solve their research problem. The results show parallel development in students IL mindset as the results of reference evaluation.

The third part of method triangulation dealt with learning outcome evaluation according to ASIIN, ABET, and ACRL criteria. ASIIN and ABET accreditation learning outcome criteria cover a wide variety of aspects. In this research, the aspect within the category ‘knowledge and understanding’ is studied. According to May and Terkowsky (2016), ASIIN emphasizes *“broad knowledge and deep understanding of mathematical and natural sciences and engineering principles as well as its interdisciplinary extensions and application-oriented knowledge about areas of specialty and a critical awareness of new findings in the discipline”*. Respectively, they claim that ABET underlines applying knowledge of mathematics, science, and engineering, ability to design and conduct experiments, as well as to analyze and interpret data, ability to design a system, component, or process to meet desired needs within realistic constraints like economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability, and ability to identify, formulate, and solve engineering problems. ABET also highlights that the broad education is necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context (May, Terkowsky 2016). The results show that the discovered learning outcomes are among those stated in the ASIIN and ABET learning outcome criteria.

ACRL Framework for information literacy for higher education (ACRL 2015) lists six concepts which are central to information literacy namely a) information authority is constructed and contextual and reflects its creator’s expertise and credibility and information should be evaluated based on the need and context in which it is used, b)

information creation is an iterative process of researching, creating, revising, and disseminating it with the aim to convey a message and is shared via a selected delivery method, c) information has several dimensions of value, d) research is iterative and depends upon asking increasingly complex or new questions, e) researchers discuss constantly new insights and discoveries, and f) searching is an iterative and often nonlinear strategic exploration and requires the evaluation of a range of information sources. Out of these criteria, all but collegial discussion can be observed in students' answers.

The third part of triangulation namely evaluation based on ASIIN, ABET, and ACRL criteria shows that integrating IL education in substance education produces learning outcomes which fulfill not only the IL learning outcome criteria but also many of engineering education quality criteria in the category of knowledge and understanding. What was not observed in this study was broad understanding of mathematical science. However, as presented in the results, students learned mathematical thinking in creating search queries. Substance and IL education supplemented each other's contents, which can be seen in students' output.

All three methods of the triangulation give parallel results about the benefits of IL education on students' IL mindset. Moreover, according to the evaluations it can also be concluded that the described kind of mechanical engineering education with an emphasis on sustainability aspects and integrated brief IL education results in a change in students' interdisciplinary – in this case mechanical engineering and sustainability – mindset. However, it cannot be determined which part of the interdisciplinary mindset change is a result of IL education and which part is caused by substance education.

In this research, the undergraduate engineering students' IL mindset change was studied. IL mindset is defined here as *understanding the entirety of the research problem and knowing when and how to utilize the available information sources and search*

techniques. The entirety here covers not only mechanical engineering but also sustainable engineering which was a central viewpoint in students' assignments.

5.5 Key findings

Based on the results of the study, even brief integrated IL education has a significant effect on students' searching skills, on their ability to understand and outline their research problem, and on the manner they formulate their information search questions to find literature for solving the research problem at hand.

Before the IL education, students formulated their research questions so that they addressed recognizing the limitations of the use of certain materials in the application and with the sustainability of the chosen materials in the given environment. After the IL education, their research questions focused on the sustainability of the applicable material options and the benefits of using certain materials. However, in this case when the mechanical engineering students' research questions were studied only one student set the research question to 'how to meet future sustainability needs'. Students also evaluated themselves the development of their understanding of the research problem. A majority agreed that their understanding of the research problem had improved during the education.

There was a clear change from searching for fact and comparison information before IL education to moving, after IL education, towards more detailed information searching where the interest was in analyzing the properties of selected materials and their use in the application. After IL education, a significantly greater number of students presented information search questions that focused on evaluating the retrieved information and how it could be used in connection with the previously acquired knowledge. Moreover, after the experience of writing a paper, their information search questions contained ideas of interacting with the retrieved information and using it in their research to create new knowledge. This is noteworthy because many university libraries have only limited human and time resources for IL education.

5.6 Novelty value of the results

The novelty in this research is in seeing IL education as a means of developing student IL mindset. The key change in their mindset concerns development in shaping information search questions regarding their research problem and understanding the depth of the research questions. Moreover, after IL education they were able to use more advanced search methods, which enabled them to get more suitable search results. In the cases in which students worked on materials selection with a special focus on sustainability challenges the formulation of their research questions showed development not only in their IL mindset but also in their sustainability mindset.

Until now, studies on higher education undergraduate engineering students' research skills have been discussing students' information searching skills. Studies of changes in engineering students' research behavior as a result of IL education have not been found nor has the concept of IL mindset been presented in literature. There is, however, some literature where students' research question understanding in connection with the research skills of social science students is mentioned (Adams 2014).

Figure 25 illustrates the traditional and renewed IL education dimensions. The traditional IL education concentrates on teaching searching skills and helping students to recognize their information need and to use information. However, in the modern IL education it is essential to teach students to think in a new way, i.e. guide them to the IL mindset which means not just knowing where and how to search but also being able to understand the research problem in its context and the knowledge of how information should be searched and used to solve that problem. In this study, IL mindset is defined as global understanding of the whole research problem and knowledge of what kind of information is needed to solve it together with knowing how to utilize available information sources and search techniques.

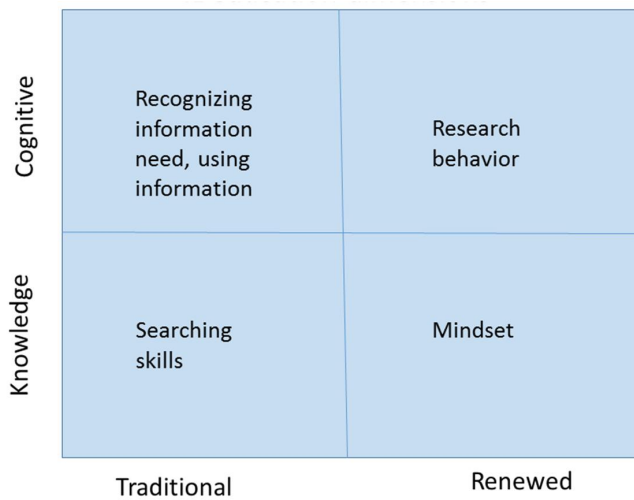


Figure 25 Dimensions of traditional and renewed IL education

5.7 Generalization and utilization of the results

The results of this research on the effects of brief integrated IL education on how students formulate their research problems and information search questions together with previous studies concerning the impact of IL education on searching skills can be used to encourage HE engineering program designers to include IL education in the syllabi of those courses on which students engage in doing research. The results can also be used to solve problems caused by limited teaching resources in university libraries. By integrating the presented kind of IL education in substance education considerable learning outcomes in both IL and research are achieved. Moreover, students' interdisciplinary mindset develops without having to involve teachers from all relating disciplines. From the engineering education point of view, the results encourage faculty to foster closer teaching collaboration with the library personnel.

5.8 Topics for future research

Further research is needed to discover those existing or new courses within the higher engineering curricula on which students engage in doing research and where brief IL education could and should therefore be integrated. Finding those courses would enable the creation of an IL education thread across the engineering education.

This research, with the exception of Course B, concerns mechanical engineering seminar courses with a special emphasis on sustainability challenges. Course B, on the other hand, is The basic course in environmental technology and thus concerns sustainability engineering. The compatibility of the results with other disciplines should be studied.

It has been shown that integrating IL education into substance education enhances students' research ability. However, doing research consists of multiple skills including scientific writing skills. Further research is needed to find out about the effects of a multidisciplinary teaching team on students' research accomplishments.

6 Summary

This research produces new scientific knowledge about the effects and impacts of brief integrated IL education on higher education students' research attainments. The focus is on undergraduate mechanical and environmental engineering students. The aim of the study was to find out what kind of changes should be made to the practice and the content of IL education in order to provide higher education students with the knowledge and skills they need in solving the engineering problems of the modern world. IL teaching resources at Lappeenranta Academic Library are limited. Therefore, IL education at LUT is carried out online for new students and for other undergraduate engineering students as brief IL education sessions that are integrated into substance education.

The original purpose of this project was to find a solution to the problem of how to teach the necessary information literacy skills needed in the modern society to an increasing number of students with resources that did not increase simultaneously. Credit-bearing IL courses arranged by the library were not an option. IL education had to be arranged some other way but yet so that students would gain the abilities they needed in their study assignments and in their future careers. Moreover, the strain of sustainability understanding in connection with all fields of engineering set new challenges to IL education because of the interdisciplinary character of students' learning assignments.

In order to create a practical teaching set for brief integrated IL education, students' pre-assignments on Bachelor's seminar were observed to determine the general limitations in their IL knowledge (Talikka et al. 2013). That information was used to create an outline for a brief IL education session that could be integrated in engineering seminar courses. In this study, the main focus was on mechanical engineering seminar courses on which students aim to find solutions to given applications in a way which meets the sustainability challenges at hand. Background and verifying information was gained from the Basic course of environmental technology and the Research methods and methodologies course. The IL education content, which was created for this study, did

not contain detailed advising of the content and use of databases or how to search them. The emphasis was in search principles and the IL mindset i.e. understanding the research problem in its context and formulating information search questions to solve the problem. The session outline proved to contain the necessary topics, which can be seen in students' wider perspective to their research.

Students answered surveys and questionnaires concerning their searching manners and ideas about their research problems and respective information search questions. The answers were transcribed and the data were analyzed using the Miles & Huberman method (Miles, Huberman 1994). The findings from the surveys and questionnaires were set against the learning outcome requirements of ASIIN (2011) and ABET (O'Hern 2012) engineering education quality evaluation criteria and the ACRL Framework for information literacy for higher education (ACRL 2015). Moreover, citation analyses were carried out in students' final papers.

One of the major findings of the study was that even brief -- in this case from 45 to 180 minutes lecture time -- integrated IL education has a substantial effect on students' searching skills. What is even more outstanding is that the effect on their ability to understand and outline their research problem and on the way they formulate their information search questions to find the right kind of literature for solving the research problem at hand is unchallengeable. Before the IL education, students' research questions concerned recognizing the limitations of the use of materials and the sustainability of the chosen material or materials. After the IL education, a greater number of their research questions concerned the sustainability of the applicable material options and the benefits of using the selected materials. The question of 'how to meet future sustainability needs' hardly appeared in the answers of students who were not majors of environmental technology but mechanical engineering students. However, it was evident that their understanding of sustainability challenges in connection with their mechanical engineering seminar assignment, i.e. their sustainability mindset, had deepened during the course.

There was also a clear change from searching for fact and comparison information before IL education to moving, after IL education, towards more detailed information searching where the interest was in analyzing the properties of selected materials and their use in the application. After IL education, a greater number of students presented information search questions, which focused on evaluating the retrieved information and on how the information could be used in connection with the previously acquired knowledge. Moreover, after writing their seminar paper, students reported that they actually searched information for interacting with the previously retrieved information and of using it in their research to create new knowledge.

When the connection between change in the research question formulation and presentation of information search questions was studied, it was found that after IL education there was a significant correlation between the formulation of the research problem and the description of the nature and content of the information needed to solve the problem.

One conclusion of the results of this work is that brief IL education is definitely worthwhile in engineering higher education. According to literature, IL education is more efficient in connection with real study tasks (Togia et al. 2012, Järvelin et al. 2015). Therefore, we can say that brief IL education sessions should be integrated in substance education where students have real assignments, which require information use. It is impossible to determine which part of the development in students interdisciplinary understanding is a result of IL education. However, there is no need to determine that because what counts is the final result: learning outcomes support students' research-related work and they learn the needed IL mindset. We can also presume that once the IL mindset is acquired, the ability to search and use information efficiently in the concept at hand remains through the future engineers' work career.

Until now, studies on higher education undergraduate engineering students' research skills have discussed their information searching skills. Studies of changes in engineering

students' research behavior as a result of IL education have not been found. There is, however, some literature where students' research questions understanding in connection with their research skills in case of social science students is mentioned (Adams 2014).

Further research is needed to discover those courses within the higher engineering curricula on which students engage in doing research and where brief IL education could and should therefore be integrated. Finding those courses would enable the creation of an IL education thread across the engineering education.

Sustainability challenges are top issues in all engineering research in the future. Therefore, it is essential to guide students to understand interdisciplinary research problems and to how information is used in solving them. This study shows that IL education enhances students' diverse vision of their research problems and thus promotes their ability to search and find solutions to them. Therefore, IL education should be merged in higher education engineering curricula and so that students could achieve the necessary attainments as early as possible. Higher education engineering curricula should also be developed so that students increasingly engage in research activities, which require independent information seeking and use.

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Appendix 1

Pilot study, Construction Materials (CM) and Research Methods and Methodologies (RMaM)

Questionnaire of information searching (1), before IL education, all students

Name:

Student number:

1. What is your research problem?
2. How and where do you plan to search information about your topic?
3. What search words do you plan to use and how do you perform the search?
4. What do you expect to get as a result?
5. How would you rate your ability to search information?

Questionnaire of information searching (2), after IL lecture, research group

Name:

Student number:

1. How and where do you now plan to search information about your topic?
2. What search words do you plan to use and how do you perform the search?
3. What do you expect to get as a result?
4. How would you now rate your ability to search information?

Questionnaire of information searching (3), after hands-on training, research group

Name:

Student number:

1. How and where did you search information about your topic?
2. What search words did you use and how did you develop your search?
3. What did you get as result? What kinds of sources did you find?
4. Do the results meet your information needs?
5. How would you now rate your ability to search information?

Appendix 2



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Tähän kyselyyn vastaavat kaikki kurssin opiskelijat. Kyselyyn vastataan ennen informatiolukutaidon opetuksen alkua. / This questionnaire is for all course participants to answer. Please, answer the questions before the information literacy education begins.

1. Vastaajan tiedot / Respondent information *

Yhteystietoja käytetään, kun tarkastellaan IL-opetuksen vaikutusta valmiin työn ominaisuuksiin. Tietoja käytetään ainoastaan tutkimustarkoitukseen. Your contact information is used when we examine the effect of IL education on the completed assignments. The information is used for research only.

Nimi, Name _____

Opiskelijanumero, Student
number _____

email _____

Koulutusohjelma, Degree
Program _____

2. Mikä on tutkimusongelmasi? What is your research problem?

3. Mistä ja miten aiot hankkia tietoa tätä tehtävää varten?

Where and how do you plan to search information about your topic?

4. Mitä hakusanoja aiot käyttää ja miten teet haun? What search words do you plan to use and how do you perform the search?

5. Mitä oletat saavasi tulokseksi? What do you expect to get as result?



BK50A2700/2

Tähän kyselyyn vastataan tiedonhakuluennon jälkeen. Please, answer these questions after the lecture on information searching.

1. Vastaajan tiedot / Respondent information

Yhteystietoja käytetään, kun tarkastellaan IL-opetuksen vaikutusta valmiin työn ominaisuuksiin. Tietoja käytetään ainoastaan tutkimustarkoitukseen. Your contact information is used when we examine the effect of IL education on the completed assignments. The information is used for research only.

Nimi, Name _____

Opiskelijanumero, Student number _____

email _____

Koulutusohjelma, Degree Program _____

2. Mistä ja miten aiot nyt hakea tähän tehtävään liittyvää tietoa? /

Where and how do you now plan to search information about your topic?

3. Mitä hakusanoja aiot käyttää ja miten teet haun? /

What search words do you plan to use and how do you perform the search?

4. Mitä oletat saavasi tulokseksi? / What do you expect to get as a result?

5. Millaisiksi arvioit nyt tiedonhakutaitosi? / How would you now rate your ability to search information?



Open your mind. LUT.
Lappeenranta University of Technology

BK50A2700/3

Tähän kyselyyn vastataan tiedonhakuharjoituksen jälkeen. Please, answer these questions after the hands-on training of information searching.

1. Vastaajan tiedot / Respondent information

Yhteystietoja käytetään, kun tarkastellaan IL-opetuksen vaikutusta valmiin työn ominaisuuksiin. Tietoja käytetään ainoastaan tutkimustarkoitukseen. Your contact information is used when we examine the effect of IL education on the completed assignments. The information is used for research only.

Nimi, Name _____

Opiskelijanumero, Student
number _____

email _____

Koulutusohjelma, Degree
Program _____

2. Mistä hait ja mistä aiot jatkaa tähän tehtävään liittyvän tiedon hakemista?
/ Where did you search and where do you now plan to continue to search
information about your topic?

3. Mitä hakusanoja ja yhdistelmiä käytit? Kuinka jatkat? / What search words did you use and how did you combine them? How do you plan to continue?

4. Mitä sait tulokseksi? / What did you get as a result?

5. Vastaako tulos tiedontarvetta? / Does the result meet your information needs?

6. Millaisiksi arvioit nyt tiedonhakutaitosi? / How would you now rate your ability to search information?

Appendix 3



BH60A0000/1

Tähän kyselyyn vastaavat kaikki kurssin opiskelijat. Kyselyyn vastataan ennen informaatiolukutaidon opetuksen alkua. [All students answer this questionnaire before IL education]

1. Vastaajan tiedot * [Respondent information]

Yhteystietoja käytetään, kun tarkastellaan IL-opetuksen vaikutusta valmiin työn ominaisuuksiin. Tietoja käytetään ainoastaan tutkimustarkoitukseen. [Your contact information is used when we examine the effect of IL education on the completed assignments. The information is used for research only.]

Nimi _____

Opiskelijanumero _____

email _____

Koulutusohjelma _____

2. Olet aloittamassa Ympäristötekniikan perusteet -opintojaksoon liittyvää harjoitustehtävää. Mistä ja miten aiot hankkia lähdemateriaalia tätä

tehtävää varten? [You are about to start working on your assignment on the Basic course in environmental technology. Where and how do you plan to find information for this assignment?]

3. Mitä hakusanoja aiot käyttää ja miten teet haun? [What search words do you plan to use and how do you plan to search?]

4. Mitä oletat saavasi tulokseksi? [What do you expect to get as a result?]



Open your mind. LUT.
Lappeenranta University of Technology

BH60A0000/2

Tähän kyselyyn vastataan tiedonhakuluennon / -harjoituksen jälkeen. [Please, answer this after the IL lecture and training.]

1. Vastaajan tiedot *

Yhteystietoja käytetään, kun tarkastellaan IL-opetuksen vaikutusta valmiin työn ominaisuuksiin.

Tietoja käytetään ainoastaan tutkimustarkoitukseen.

Nimi, Name _____

Opiskelijanumero, Student
number _____

email _____

Koulutusohjelma, Degree
Program _____

2. Mistä ja miten hait tietoa aiheestasi? [Where and how did you search]

3. Mitä hakusanoja käytit ja miten muokkasit hakuasi? [What search words did you use and how did you modify your search?]

4. Vastaavatko tulokset tiedontarvettasi? [Were the references relevant?]

6. Millaisiksi nyt arvioit tiedonhakutaitosi? Opitko uutta? Jos, niin mainitse jokin uusi asia, jonka aiot ottaa tästä edes käyttöön tiedonhakutehtävissä. [How do now rate your information searching competence? Did you learn something new that you plan to utilize in your future search assignments?]

Appendix 4

Questionnaire 1, Feb 10, 2016,

Course C: BK50A2700 Selection criteria of structural materials

Name:

Research question – information searching question/s

| | |
|----|--|
| 1. | In connection with this task, what is your research question? |
| 2. | What are the questions that you want the searched information to answer? |

| | |
|----|--|
| 3. | Where do you plan to search? |
| 4. | What are your search words? How do you plan to search? |

Questionnaire 2, March 16, 2016, BK50A2700 SELECTION CRITERIA OF
STRUCTURAL MATERIALS

Name:

Research question – information searching question/s

| | |
|----|---|
| 1. | In connection with this task, what is your research question? |
| 2. | What were the questions that you wanted the searched information to answer? |
| 3. | Where did you search? |

| | |
|----|--|
| | |
| 4. | What were your search words? How did you search? |
| 5. | Was the result satisfactory? |

Questionnaire 3, BK50A2700 SELECTION CRITERIA OF STRUCTURAL MATERIALS

Name:

Team:

Research question – information searching question/s

| | |
|----|---|
| 1. | Did your research problem change or become more precise during the process? If so, how? |
| 2. | Did you get IL education at the right time? |
| 3. | Did you get enough IL education? Time and content. What should there have been more / less? You may continue on the other side of the paper if necessary. |

| | |
|----|--|
| 4. | What were your search words? What was the connection between search words and keywords? |
| 5. | Did you search mainly a) general information <input type="checkbox"/> b) detailed information <input type="checkbox"/> |
| 6. | How do you justify that the information searching result was satisfactory? |
| 7. | Evaluate your team's unity. Grades 0-5, 0=none and 5=excellent |

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