TOWARDS INTEGRATED SCIENCE EDUCATION THROUGH COLLABORATIVE PROJECT-BASED LEARNING

TEACHERS' PERCEPTIONS, EXPERIENCES AND PRACTICES

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STRUCTURE OF THE PRESENTATION

Aim & Rationale

Main Theoretical Concepts

Research method & studies

Main findings and conclusions

AIM & RATIONALE

Concerns about the state of science education

(e.g., NRC, 2010; Osborne & Dillon, 2008)

Students' lack of interest towards school science and science careers, especially chemistry

(PISA, 2007; ROSE 2006)

Interest in integrated science education (ISE)

- To teach the competences of the 21st century
- For making science education more relevant

(e.g., Bell, 2010; Bennett et al., 2007; Czerniak & Johnson, 2014; Li et al., 2020)

ISE is promoted in education policies

- Across the globe

(Lyons, 2020; NRC, 2013; Wei 2009)

- The national curricula & LUMA strategy in Finland

(EDUFI, 2016; MOEC, 2021)

AIM & RATIONALE

More research is needed if we are to move towards integrated science education (ISE)

- A lack of consensus on ISE

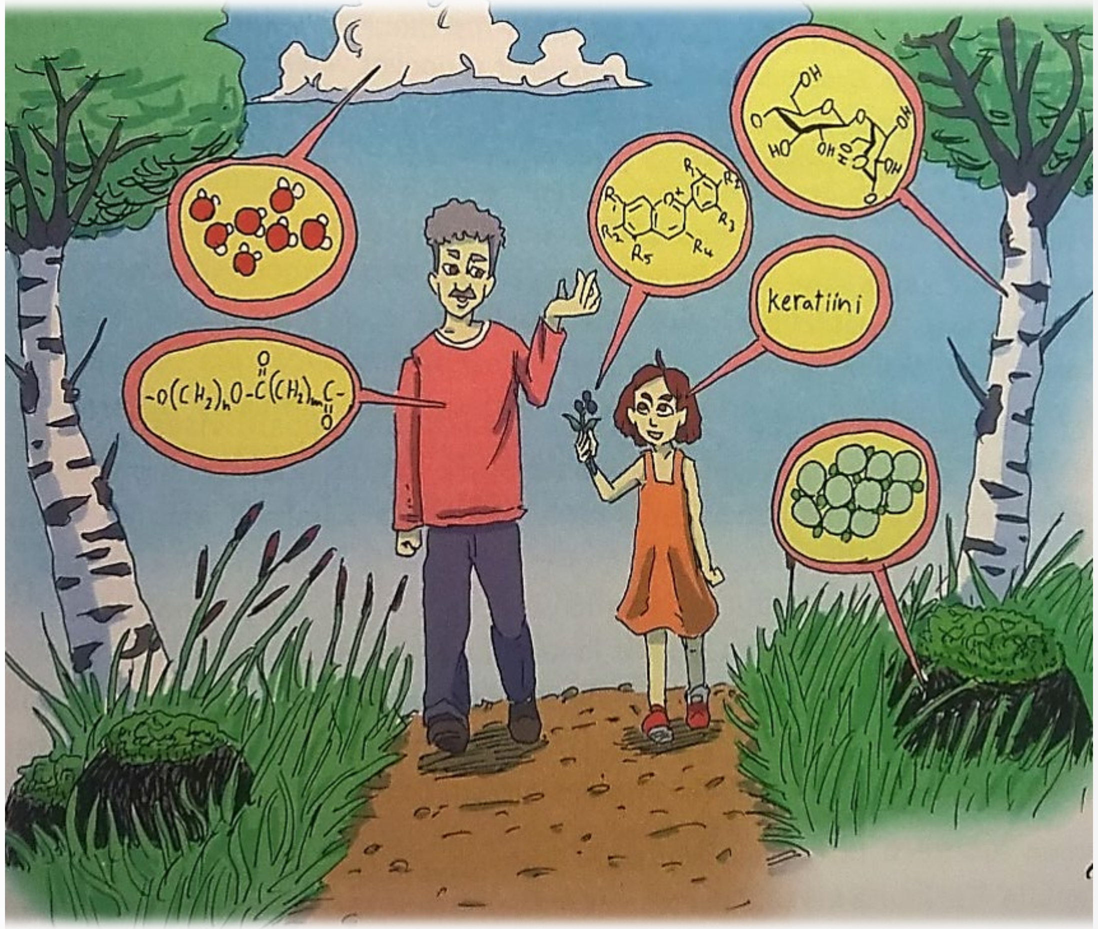
  (Czerniak & Johnson, 2014; Klein, 2017; Lyons, 2020)

- Implementing ISE is challenging

  (Margot & Kettler, 2019; Samson, 2014)

- Teachers' perceptions influence their science education practices

  (Burmeister, Schmidt-Jacob & Eilks, 2013; Czerniak & Lumpe, 1996; Jones & Leagon, 2014)



Picture: Pekka Isometsä

AIM & RESEARCH QUESTIONS

The aim of this thesis is to understand teachers' perceptions, experiences and integrative practices to better promote integrative science education at different education levels by supporting teachers

1

How do science teachers perceive integrated education and project-based learning?

2

What kind of experiences do science teachers have of integrated practices?

3

What kind of integrated practices do science teachers have?

MAIN THEORETICAL CONCEPTS

INTEGRATED SCIENCE EDUCATION

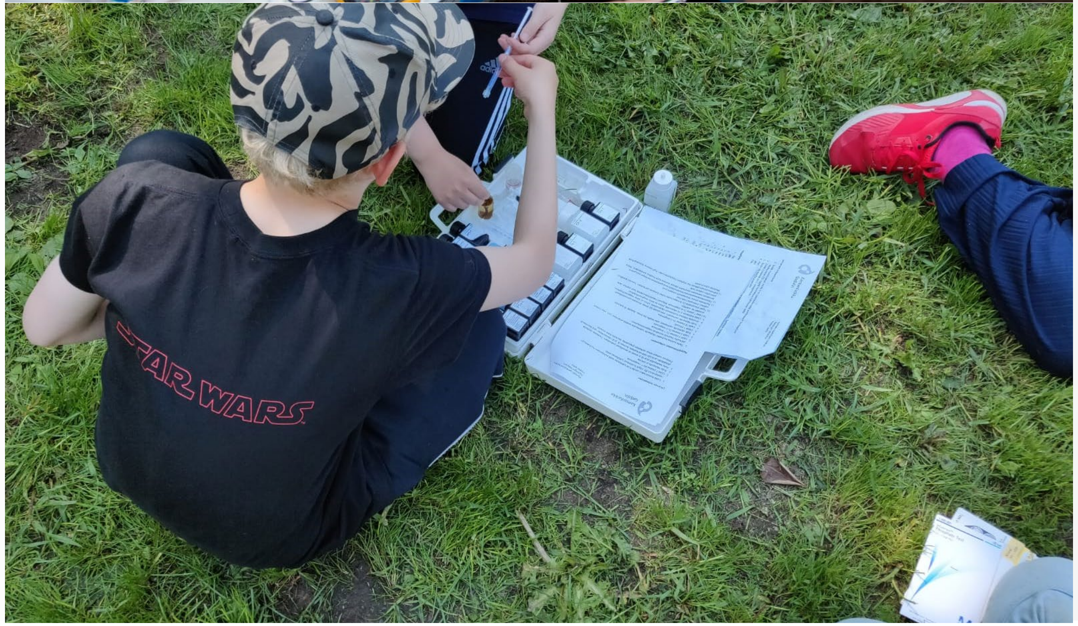
COLLABORATIVE PROJECT-BASED LEARNING

TEACHERS' PERCEPTIONS AND SELF-EFFICACY

INTEGRATED SCIENCE EDUCATION (ISE)

An effort to organize or integrate science curriculum content into a meaningful whole by a constructive and context-based approach that crosses subject boundaries and links learning to the real world

(Åström, 2008; Beane, 1997; Czerniak & Johnson, 2014).



Picture: StarT-festivals / LUMA Centre Finland (above), LUMA science camp / Veronica Winquist (below)

COLLABORATIVE PROJECT-BASED LEARNING (PBL)

A student-centred, teacher-facilitated pedagogical approach that organizes learning around clearly defined projects and includes collaboration at all project phases.

(Bell, 2010; Han et al., 2015; Kokotsaki et al., 2016; Thomas, 2000)

Elements of PBL
Student learning goals derived from curriculum
Centrality of the learning process
Authentic & meaningful context of learning
Creation of project artifact
Collaborative learning
Constructive prosess
Engaging to students
Scaffolding instruction
Formative assessment
Publicity & presentation of the project

TEACHERS' PERCEPTIONS

Quick and intuitive cognitions or presumptive thoughts of a concept. (Smith, 2001)

TEACHERS' SELF-EFFICACY

Teachers' self-efficacy is a context-specific judgment or a belief of one's capabilities to organise and execute the courses of action required to produce certain educational attainments. (Bandura, 1997)

A part of teachers' educational belief system that is composed of various educational beliefs and it is according to these connections that beliefs are prioritized and have context-specific effects (Pajares, 1992).

A MIXED-METHOD RESEARCH

Provides a more holistic understanding as it utilizes both qualitative and quantitative research approaches.

(Ayiro, 2012; Denscombe, 2010; Johnson et al., 2007)

THE ORIGINAL PUBLICATIONS

I. Turkka, J., Haatainen, O., & Aksela, M. (2017). Integrating art into science education: A survey of science teachers' practices. *International Journal of Science Education*, 39(10), 1403–1419. https://doi.org/10.1080/09500693.2017.1333656

II. Haatainen, O., Turkka, J., & Aksela, M. (2021). Science Teachers' Perceptions and Self-Efficacy Beliefs Related to Integrated Science Education. *Education Sciences*, *11*(6), 272. https://doi.org/10.3390/educsci11060272

III. Haatainen, O. & Aksela, M. (2021). Project-Based Learning in Science Education: Active Teachers' Perceptions and Practices. *LUMAT: International Journal on Math, Science and Technology Education, 9*(1), 149–173. https://doi.org/10.31129/LUMAT.9.1.1392

IV. Haatainen, O., Aksela, M. & Lavonen, J. (2021). Teachers' Design Principles for Integrated Science Education. (manuscript submitted)

A MIXED-METHOD APPROACH

	Study I	Study II	Study III	Study IV
Research method	Survey	Survey	Survey, case study	Case study
Data collection	November 2015, through mailing lists and Facebook groups (studies I and II together)		January to March 2017, through the StarT online reporting form	February 2020, within an online teacher training course
Data	Qualitative-led questionnaires	Mixed questionnaires	Qualitative-led questionnaires & reports	Questionnaires & course assignment
Analysis	A qualitative content analysis (Mayring, 2014), an exploratory statistical analysis (Cohen et al., 2007)	An exploratory statistical analysis (Cohen et al., 2007), an exploratory factor analysis, a qualitative content analysis (Mayring, 2014).	An interpretive, theory-driven content analysis (Drisko & Maschi, 2015; Mayring, 2014)	A qualitative content analysis (Mayring, 2014), an exploratory statistical analysis (Cohen et al., 2007)

RESEARCH QUESTIONS (RQ) AND THE ORIGINAL PUBLICATIONS

RQ1: Teachers' perceptions and beliefs in regards to ISE

Study II: ISE and self-efficacy

Study III: the advantages and challenges of implementing PBL

Study IV: the design principles for ISE

RQ3: Science teachers' integrated practices

Study I: science and art integration

Study III: PBL practices

RQ2: Teachers' experiences

Study I: science and art integration

Study II: ISE

Study IV: ISE and PBL

MAIN FINDINGS PER RESEARCH QUESTION AND CONCLUSIONS

RQ1: HOW DO SCIENCE TEACHERS PERCEIVE ISE AND PBL?

RQ1: Teachers' perceptions and beliefs

Study II: ISE and self-efficacy
Study III: the advantages and challenges of implementing PBL

Study IV: the design principles for ISE

- Teachers' perceptions varied.
- ISE and PBL are relevant but difficult to implement
- Self-efficacy emerged as a key factor explaining teachers' perceptions of and their lack of confidence in implementing ISE

"Integrated education combines the school, world and daily lives together… learning will happen from the perspective of multiple disciplines, students' daily lives and even working life"
(Study II, Teacher 32)

RQ2: WHAT KIND OF EXPERIENCES DO SCIENCE TEACHERS HAVE OF INTEGRATED PRACTICES?

RQ2: Teachers' experiences

Study I: science and art integration
Study II: ISE

Study IV: ISE and PBL

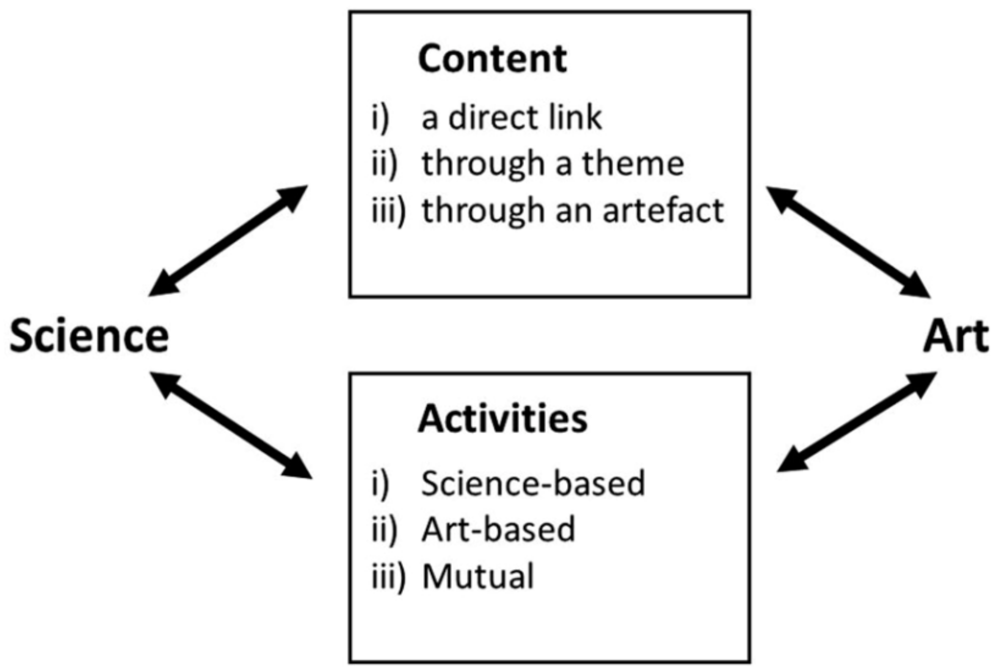
- Teachers' experience with integrated practices varied greatly.
- Secondary school science teachers in Finland have little experience with integrated practices such as PBL and collaboration with colleagues or with parties beyond school.
- Teachers' experiences with integrated activities and interdisciplinary collaboration correlate with their views of ISE, challenges and self-efficacy beliefs.

RQ3: WHAT KIND OF INTEGRATED PRACTICES DO SCIENCE TEACHERS HAVE?

RQ3: Science teachers' integrated practices

Study I: science and art integration
Study III: PBL practices

- A framework of teachers’ practices of integrating art in science education through content and activities
- Teachers’ PBL practices seem to be lacking in certain key features, for example in relation to assessment and reflection.



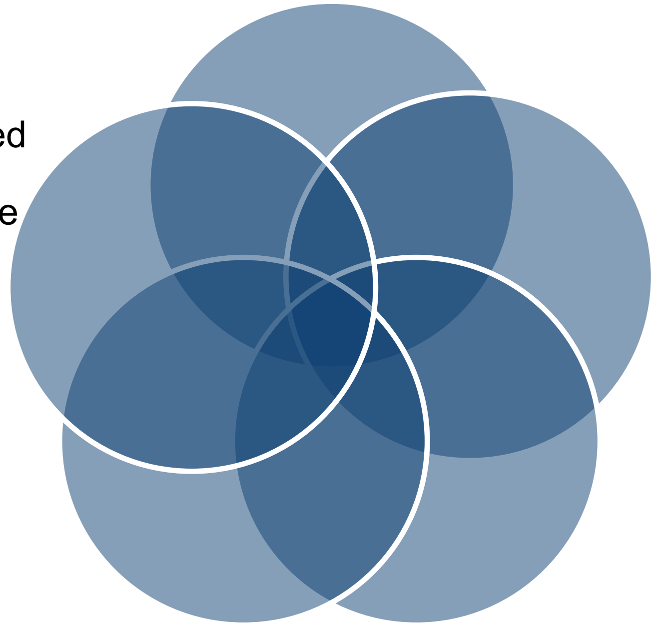
PEGAGOGICAL MODEL FOR ISE

A feasible model for ISE is one that
1. corresponds with research findings
2. is relevant for science education
3. is perceived as feasible by teachers.

In the model ISE is what occurs in the middle, when all 5 principles have been accounted for. Curriculum forms the frame for the model and need to be addressed when implementing ISE.

Coherence in integration
Including core concepts from integrated subjects, transversal competencies and building coherent knowledge structures

Relevance of learning
through context-based approach and a connection to real-life and vocations



Engage students in constructing knowledge
through collaborative student-centred approaches (i.e. inquiry- or project-based learning)

Knowledge practices
(i.e. scientific, engineering or technological practices)

Versatility
in instructions, assessment and learning environments

CONCLUSION

Towards integrated science education

Feasible pedagogical models	Education for pre-service and in-service teachers

↓

Science teachers

Positive experiences	Perceptions and self-efficacy

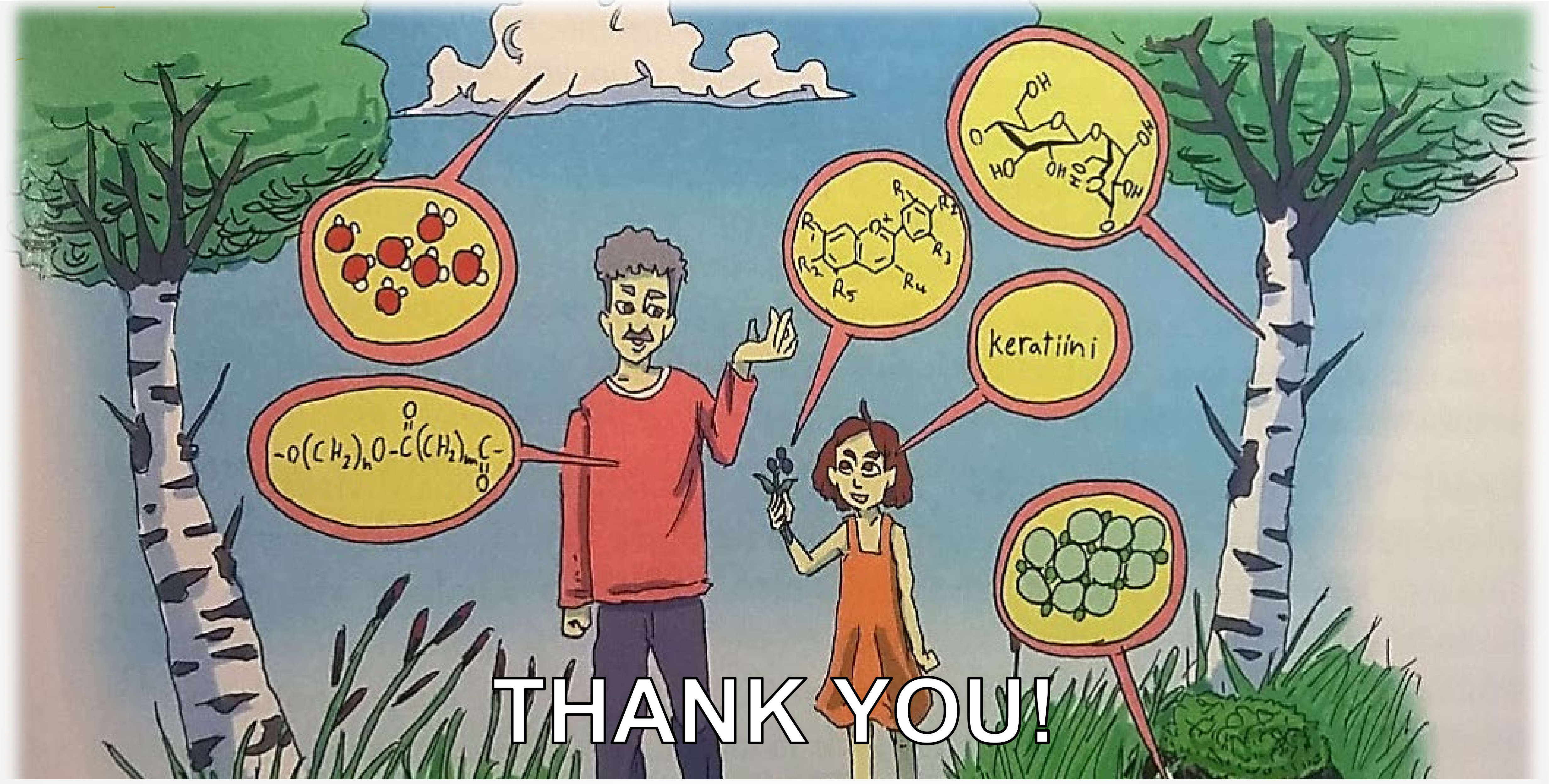
↓

Integrated Practices

Supporting teachers through

1. educational programmes
2. by providing feasible pedagogical models for ISE

can have a positive effect on teachers’ perceptions, experiences and self-efficacy beliefs that in turn affect teachers’ willingness to implement more integrated practices.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APPENDICES

Study I (p.1409)

Table 1. Previous case studies that report art and science integration

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Arts	Subjects involved	Task descriptions	Science topics
Design	STEAM	Engaging students with functional design processes	Engineering process (Bequette & Bequette, 2012)
Paintings	Chemistry	Experimental activities on dyes and colours, and information about chemistry in paintings	Chemistry concepts (Kafetzopoulos, Spyrellis, & Lymperopoulou-Karaliota, 2006)
Photography	STEAM	Students do inquiries of how science relates to aesthetic properties or students build their own pinhole cameras	Inquiry, chemical kinetics and optics (Stamovlasis, 2003)
Drawing	Mathematics and physics	Students are introduced to art as a way of expressing mathematics and science. Students write and draw to express their ideas	The abstract concepts of contemporary physics (van der veen, 2012)
Concept cartoons	Physics, chemistry and biology	Students discuss (and occasionally draw) concept cartoons which introduce characters who represent different abstract scientific ideas or arguments	Chemical bonding (Ültay, 2015)
Comics	Biology	Comics are used to engage students	Viruses (Spiegel, McQuillan, Halpin, Matuk, & Diamond, 2013)
Sculpture (glass, metal and ceramics)	STEAM	Collaborative projects with artists	Concepts of protein structure and folding (Gurnon, Voss-Andreae, & Stanley, 2013)
Literature	Biology	Students write short stories related to science	Enhances scientific literacy (Ritchie, Tomas, & Tones, 2011)
Poetry	Chemistry	Students read, analyse and write poems	Atomic radius and ionisation energy (Araújo, Morais, & Paiva, 2015)
Drama	Physics and biology	Role plays and physical simulations	Electrolysis of water (Saricayir, 2010) Learning about socio-scientific issues and nature of science (Ødegaard, 2003)
Dance and movement	Science and mathematics	Kinesthetic activities and dance.	Geometry (Moore & Linder, 2012)
Music	Science, chemistry and physics	Listening and analysing science content songs	Science topics (K-12) (Crowther et al., 2016) and various topics of chemistry (Last, 2009)
Film and cinema	Science	Videography	Videographic investigations of energy geography (Graybill, 2016)

Study I (p.1413)

Table 2. Science teachers' participation in science and art integration.

Questions (options to answer were yes/no)	%/($N = 66$)
I organise science and art integration on my classes (alone or in cooperation with others)	28
I organise (or participate in organising) courses or activities which integrate science and art	27
The atmosphere in our school encourages integrating art and science	53
I do not have enough time to organise integration of science and art	45
I do not know enough to organise integration of science and art	52
I would like to have more material to help me integrate science and art	73

Study I (p.1414)

Table 3. The frequency of integrating science and art.

How often do you employ the following in your classes? ($N = 66$)	Never (%)	Once a year (%)	1–2 times during a course (%)	More frequently (%)
Works of art as context	36	35	20	6
Methods of art as a context	42	27	20	8
Talking about the connection between art and science	39	35	15	8
Talking about art and science in a bigger picture (e.g. a phenomenon)	59	21	11	5
Creating projects that include art	56	24	12	5
Fine art activities (e.g. drawing, painting)	36	27	18	12
Drama activities (e.g. bodily exercise or a performance)	47	32	17	2
Digital art or video activities (digital narratives, producing videos)	52	27	18	0
Literature activities (writing poetry or creative writing)	70	20	6	2

Study I (p.1414)

Table 4. The frequency of categories of accepted art integration examples.

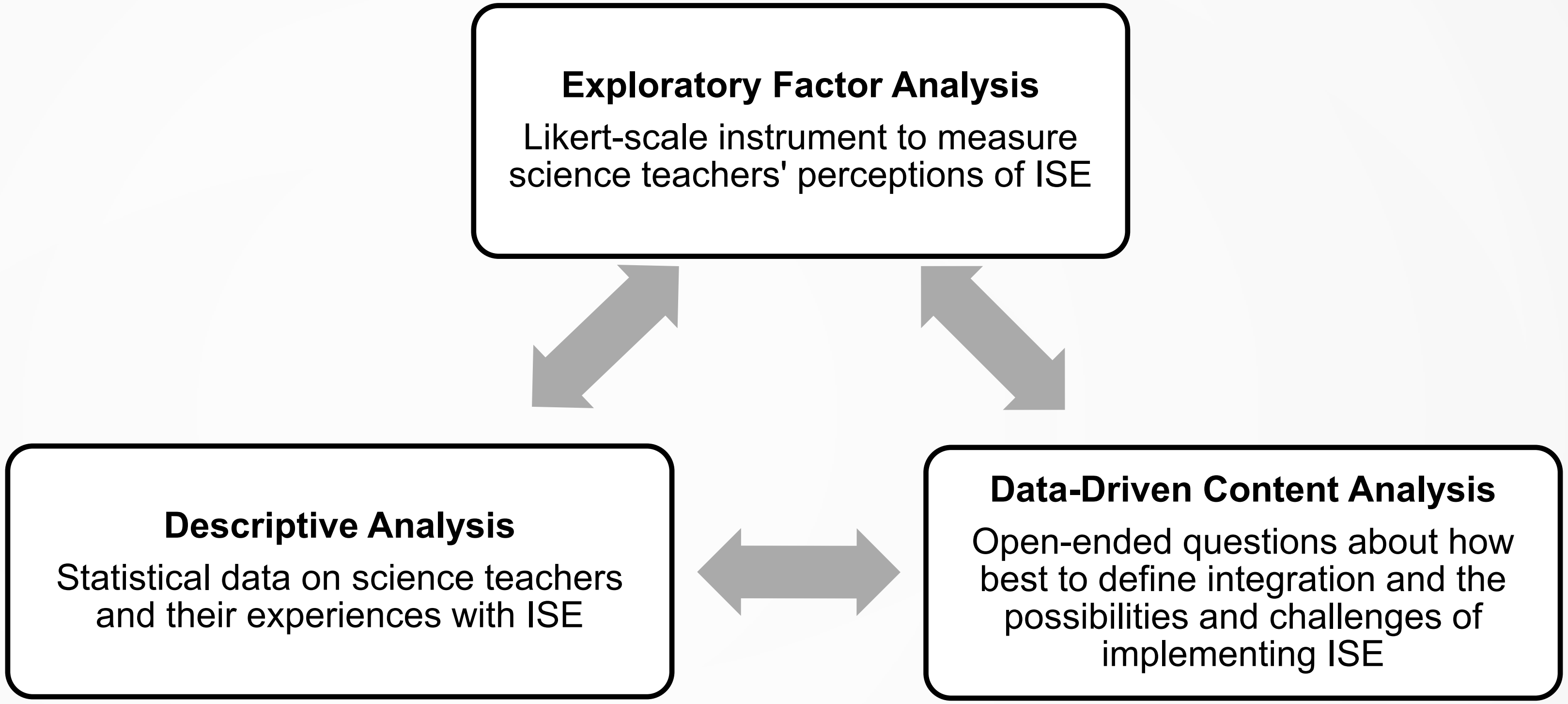
Label	Number of cases ($N = 65$)	Frequency (%)
Activity of science	9	14
Activity of art	18	27
Activity for both	13	20
Content through a theme	4	6
Content through an artefact	12	18
Content with a direct connection	9	14

STUDY II

Study II, p. 5/20 Figure 1.

Data Collection: Online Survey

Administered to active teachers via mailing lists and Facebook groups for science teachers



Research Questions

How do science teachers perceive ISE?

How do science teachers perceive of their self-efficacy in relation to ISE?

Do science teachers’ self-efficacy beliefs about ISE correlate with their experiences with and perceptions of ISE?

STUDY II, P. 6/20

Table 1. Number of science and mathematics teachers in basic and general upper secondary education in Finland and in the survey (respondents).

	Number of teachers in Finland[1]	Respondents	Respondents (% of teachers)
Basic education[2]			
Mathematics or data science	1677	32	1.91
Science[3]	1310	25	1.91
Other	23659	11[4]	0.05
Total	26646	68	0.26
General upper secondary education			
Mathematics or data science	760	10	1.32
Science[3]	678	12	1.77
Other	3779	0	0.00
Total	5217	22[5]	0.42

[1] Source: Vipunen – Education Statistics Finland (https://vipunen.fi/en-gb/). Personnel, statistical year 2016, survey response rate 66%.
[2] Includes teachers in primary and/or lower secondary schools.
[3] Science subjects included biology, physics, chemistry, geography, and environment and nature studies.
[4] All respondents were classroom teachers providing primary education.
[5] Eight teachers providing both lower and upper secondary education are reported in the number of upper secondary education teachers.

STUDY II, P. 9/20, TABLE 2. MULTIFACETED NATURE OF INTEGRATION

Factor F4 variables (factor loading)	Examples of science teachers' definitions of integrated education (IE)	Categories of IE	Freq (%)
Student-centred approach is essential in IE (0.68)	'Teaching disciplines through students' lives and their experiences.' (Teacher 39) 'Personally meaningful for the students.' (Teacher 59) 'Help and support the students according to their individual needs.' (Teacher 74)	Student-centred	7.1
IE should be linked to students' daily lives and to society (0.57) In IE, one must apply the skills and knowledge learned within the context of everyday life (0.55)	'The understanding of the wholeness of issues influencing peoples' living environment.' (Teacher 44) 'Integrated education combines the school world and daily lives together, in which case the learning will be done from the perspective of multiple disciplines, students' daily lives and even working life.' (Teacher 32)	Everyday life	7.1
IE requires collaboration between subjects (0.46)	'Discussing phenomenon-based issues that cross subject boundaries. The aim is to understand the links and dependencies between different contents of learning.' (Teacher 18) 'Integrated education refers to crossing subject boundaries and teaching doesn't necessarily happen in school.' (Teacher 32)	Interdisciplinary	21.3
	'Learning about health education, home economics, biology and environmental issues in chemistry. Traffic, physical education, etc., together with physics. Math can be applied within all in appropriate places.' (Teacher 82) 'In practice, this means that in mathematics teaching, one can use examples from other subjects and in other subjects use mathematics.' (Teacher 97) 'Learning about a common topic in both subjects, discarding overlapping matter.' (Teacher 2)	Multidisciplinary	7.9
In IE, it is essential to examine the complexity of a phenomenon comprehensively (0.45)	'Teaching forms a logical whole, in which facts link to each other either within traditional subjects or between them. The learning content forms an integrated [whole].' (Teacher 90) 'Students form an integral understanding of concepts and contents.' (Teacher 52)	Wholeness	21.3
	'An interesting issue defines the direction of teaching and the skills to be learned.' (Teacher 54) 'Phenomenon-based education, where matters of several subjects are learned at the same time.' (Teacher 85)	Phenomenon-based	16.5
	'A student can link knowledge and skills across disciplines and within discipline. … Math, physics and chemistry are a difficult combination, as people begin to have their thumbs in their palms. You need to know the basics of the subjects and then you can start to innovate...' (Teacher 31) 'It is rehearsal of previously learned [subject matter], adding, deepening and applying it.' (Teacher 100)	Subject-based	10.2
		Other	4.7
		Total	100

STUDY II, P. 10/20, TABLE 3. RELEVANCE

Factor F2 variable (factor loading)	Examples of science teachers' perceptions of POSS	Categories of POSS	Freq. (%)
I would like to use more integrated approaches in my teaching (0.86)	'All the pupils like this method of working. It is also inspiring for myself.' (Teacher 53) 'Motivation increases when one can apply what one has learned in new situations.' (Teacher 100).	Motivation	22.0
I think it is important to implement integration within my own teaching (0.82) I think IE is a suitable method to teach the subjects that I am teaching (0.69)	'The meaningfulness of learning increases.' (Teacher 19) 'Students can get a better understanding of the fact that chemistry is part of everyday life.' (Techer 98) '[Students] can apply things to their daily lives and studies.' (Teacher 5)	Meaningful	13.0
	'It adds a new perspective to one's teaching and one is also learning him/herself.' (Teacher 8) 'Special emphasis is on data acquisition and presentation. The use of ICT is easily incorporated into work.' (Teacher 88)	Variety	8.0
	'Increases well-being at school.' (Teacher 26) 'Students' personal growth in becoming independent.' (teacher 89) 'Joy of learning.' (Teacher 34)	Well-being	8.0
	'Only the sky is the limit … student-centred and inquiry-based learning can be better executed, room for students' interests and creativity.' (Teacher 81) 'Students learn from each other, which is a very good thing!' (Teacher 7)	Student-centred	4.0
IE helps students to understand the interconnected nature of issues better than traditional education (0.68)	'The overlapping content of different subjects can be utilised better. The fact that one has learned something in chemistry does not mean one could not study it again in physics. When students realise that they have already learned this in a different context, the "overload" decreases.' (Teacher 30) 'Issues and phenomena will form entities, and all will be linked together.' (Teacher 12)	Integrity of knowledge	27.0
With IE, one can achieve better learning outcomes than with traditional education (0.61)	'Team working skills develop for all involved.' (Teacher 38). 'One learns to pursue knowledge, edit tables and draw conclusions. One learns to apply mathematics.' (Teacher 82) 'One can get absorbed in one's topic more thoroughly.' (Teacher 68)	Learning Outcomes	13.0
		Other	5.0
		Total	100

STUDY II, P. 11/20

Table 4: The frequencies of science teachers' views on the essential aims of integrated science education (ISE).

Aims associated with ISE	freq	freq (% of occurrences)	freq (% of teachers)
Understanding the nature of science and 'how science is done'	19	7.42	20.00
Teaching the subject contents as integrated modules	49	19.14	51.58
Student's growth as an individual	27	10.55	28.42
Learning skills and knowledge needed for everyday life	46	17.97	48.42
Learning skills and knowledge needed from the societal perspective	38	14.84	40.00
Mastery of the subject content (including skills and knowledge)	26	10.16	27.37
To motivate students to study mathematics and science	49	19.14	51.58
Other (specified as collaboration)	2	0.78	2.11
Total	256	100.00	269.47

STUDY II, P. 12/20, TABLE 5. CHALLENGES & TEACHERS' SELF-EFFICACY

Factor variable (factor loading)	Examples of science teachers' perceptions of CHAL	Categories of CHAL	Freq. (%)
F3: Implementing integrated education is more laborious than traditional education (0.85)	'The laboriousness of planning [integrated lessons].' (Teacher 67) 'Finding suitable topics that offer enough, yet not too much, material. I will have to be the one to find all of the reading tasks, invent topics for art and guide writing essays, etc. …' (Teacher 68) 'Acknowledge all the students adequately.' (Teacher 59)	Implementation	13.7
F3: Integrated lessons require more time from the teacher than carrying out traditional lessons (0.86)	'More time is spent guiding personal project work and [with] assessment. There are also many meetings.' (Teacher 82) 'Planning takes time.' (Teacher 42)	Resource-Time	24.2
F3: Because of a lack of time, implementing integrated education in collaboration with other teachers is difficult (0.46)	'Larger collaboration requires greater personal input outside teaching time, especially at the beginning.' (Teacher 43) 'Scheduling my own teaching with other teachers, teaching groups and issues to be dealt with. Even though there is enthusiasm, good plans are only partly executed because of a lack of time and different schedules.' (Teacher 94)		
	'Courses that could have a lot in common are offered to students in different periods.' (Teacher 30) 'It requires special arrangements from the principal and more resources also for planning.' (Teacher 8)	Administration	25.0
	'…one can't execute integration because of the large number of students, and it is impossible to arrange decent sized groups in a manner that allows students into all the courses at the same time. We have even tried to execute an integrated unit with four teachers and four different disciplines, but we did not manage to make the students choose all the required courses at the same time. The current structure should be dismantled for authentic integration to be possible.' (Teacher 64)		
	'Most materials are meant for subject teaching.' (Teacher 43) 'It is difficult to choose the proper materials from all the material out there.' (Teacher 34)	Resource-Other	9.7
	'At the moment, in lower secondary schools people are stuck in their own cubicles teaching their own subjects. Integrated education happens mostly just as talk.' (Teacher 51). 'Students are too conservative and beg for subject boundaries.' (Teacher 12)	Attitude	11.3
	'Small pupils have relatively few skills for working autonomously.' (Teacher 88) 'Basic chemistry must be mastered before teaching can be integrated with other disciplines, such as biology, home economics or physics.' (Teacher 92)	Competence	6.5
F1: Teachers' self-efficacy for ISE	'[All teachers must have…] also internalized the method on some level'. (Teacher 38) 'Teacher's knowledge and skills must be sufficiently broad in order to make teaching truly integrated instead of just binding a single lesson to part of a whole unit.' (Teacher 43)		
		Other	7.3
		Total	100

STUDY II, APPENDIX 1, P. 16/20

Table A1: Science teachers' experience with teaching, integrated practices and collaborating with colleagues

Science teachers' teaching experience

	Over 10 years	6–10 years	3–5 years	1–2 years	Less than a year	Total
Teaching experience	72	11	9	2	1	95
Teaching experience (%)	75.8	11.6	9.5	2.1	1.0	100.0

Science teachers' experience in integrated education

	Never	1–2 times per year	3–5 times per year	Over 5 times per year	1–2 times per month	Over 2 times per month	Total
Integrated practices							
Parallel subjects	19	37	9	10	8	10	93
Periodic subjects	16	16	17	17	5	18	89
Integrated activities	6	43	22	15	3	4	93
Total	41	96	48	42	16	32	275
Total (%)	14.9	34.9	17.5	15.3	5.8	11.6	100.0
Collaboration with colleagues							
Within the subject	16	25	19	13	6	14	93
Interdisciplinary	26	38	14	8	3	3	92
Total	42	63	33	21	9	17	185
Total (%)	22.7	34.0	17.8	11.4	4.9	9.2	100.0

STUDY II, APPENDIX 2, P. 17/20

Variables	Factor 1	Factor 2	Factor 3	Factor 4	Commu-nalities
<u>1.Factor: Self-efficacy</u>					
I possess a sufficient amount of knowledge to implement IE.	-0.86				0.71
I don't need any support for implementing IE.	-0.82			-.20	0.64
I can plan and execute integrative learning modules.	-0.77				0.66
I have adequate skills to implement IE.	-0.72			-.27	0.60
I don't need more integrative teaching material for implementing IE.	-0.66				0.40
Taking integrative instructions into account in my own teaching is easy for me.	-0.62	0.29			0.60
I know enough about other subjects to implement IE.	-0.60	-0.22			0.44
<u>2. Factor: Relevance</u>					
I would like to use more integrated approaches in my teaching.	0.23	0.86			0.65
I think it is important to implement integration within my own teaching.		0.82			0.73
I think IE is a suitable method to teach the subjects that I am teaching.	-0.25	0.69			0.59
IE helps students to understand the interconnected nature of issues better than traditional education.		0.68			0.57
With IE, one can achieve better learning outcomes than with traditional education.		0.61	-0.25		0.60
<u>3. Factor: Challenges</u>					
Integrated lessons require more time from the teacher than carrying out traditional lessons.			0.86		0.66
Implementing integrated education is more laborious than traditional education.			0.85		0.66
Implementing integrated education requires cutting down on subject content.			0.50		0.40
Because of a lack of time, implementing integrated education in collaboration with other teachers is difficult.			0.46		0.33
<u>4. Factor: Multifaceted nature of integration</u>					
A student-centred approach is essential in IE.				0.68	0.42
IE should be linked to students' daily lives and to society.				0.57	0.36
In IE, one must apply the skills and knowledge learned within the context of everyday life.			0.30	0.55	0.44
IE requires collaboration between subjects.				0.46	0.25
In IE, it is essential to examine the complexity of a phenomenon comprehensively.				0.45	0.29
<u>Total variance explained by the factors (squared loadings. %)</u>					52.46
1.Factor: Self-efficacy					23.04
2. Factor: Relevance (of IE)					16.43
3. Factor: Challenges (of IE)					7.94
4. Factor: Multifaceted Integration					5.06

Extraction Method: Principal Axis Factoring with a fixed number of factors.
Rotation Method: Promax with Kaiser Normalisation. Rotation converged in 5 iterations.
Note: all loadings < 0.2 were omitted.

STUDY II, APPENDIX 3, P. 17/20

Table A3: Descriptive statistics for the four factors relating to science teachers' conceptions of integrated education (N=89) and the factor correlation matrix (the negative factor loadings of F1 have been taken into account in the factor correlations).

	N of items	Mean	SD	Variance	Skewness	Kurtosis	Cronbach's alpha	Factor correlation matrix			
								F1	F2	F3	F4
F1. Self-efficacy	7	3.20	0.84	0.71	0.07	-0.45	0.874	1.00			
F2. Relevance	5	3.92	0.81	0.66	-1.00	0.77	0.858	0.12	1.00		
F3. Challenges	4	3.69	0.82	0.67	-0.63	0.30	0.765	-0.35	-0.32	1.00	
F4. Multifaceted Integration	5	4.17	0.58	0.33	-0.58	-0.42	0.688	0.11	0.44	-0.13	1.00

Extraction Method: Principal Axis Factoring.
Rotation Method: Promax with Kaiser Normalisation.

STUDY III

STUDY III, TABLE 1, P. 152

The project-based learning (PBL) design principles adapted from Condliffe et al. (2017), Kokotsaki et al. (2016) and Savery (2019).

Elements	Description
Student learning goals	The content of a PBL study unit that ensures the successful implementation of PBL as part of science education. The project should be focused on teaching students' key concepts, knowledge practices and understanding derived from national curriculum or standards and subject matter content as well as transversal competencies.
Centrality of the project	This feature distinguishes PBL from other instructional approaches: project is not the culmination of learning, but instead in the PBL approach, the project is seen as a process through which learning new contents and skills takes place.
Contextual	PBL is a contextualized approach to learning. The projects should be authentic, meaningful, and related to a real-world context or an interdisciplinary theme and be connected to students' own concerns and interests. Furthermore, projects require a well-designed and open-ended driving question or problem, at the appropriate level of challenge for students that serves to organize all the project activities.
Project artefact	The project activities should involve the creation of a final tangible product that addresses the driving question and offers representation of students' learning.
Collaborative learning	PBL requires social negotiation of knowledge, working collaboratively in a group, to develop possible solutions to the problem or project. Collaboration should be seen as a means to reach the goals and it should be a feature of all project stages. This can include collaboration with parents, other schools, companies and science experts.

Elements	Description
Constructive	PBL involves students in a process of constructing knowledge that can be achieved through in-depth inquiry, use of problem-solving and critical thinking skills and by revision of what is currently known and what needs to be understood before proceeding.
Student engagement	Teachers should foster student engagement during the project process. Students' choice and active participation is vital for the construction of knowledge. Although encouraging student choice align with student-centred approaches, it is not explicitly clear what the extent of student autonomy should be in a PBL classroom.
Scaffolding instruction	Scaffolding instruction refers to any method or resource (e.g., teachers, peers, learning materials and technologies) used by teachers to help students to accomplish more difficult tasks than they would be capable of completing on their own. The key elements of scaffolding are: 1) the scaffold needs to be tailored to a student's current level of understanding, and 2) scaffolds should be faded over time as students learn to apply their new knowledge or skills on their own.
Assessment	Emphasis should be on formative assessment that aims at supporting students' learning. This includes reflection, self and peer evaluation and teachers' feedback throughout the project process. Assessment should also include a specific end-of-project phase that ensures reflection on what was learned as well as the creation of a project product that addresses the driving question.
Publicity	A public presentation of the project supports students' communication skills and can motivate students and present an opportunity for feedback. Instead of a presentation, the product itself can be made public. This can also be seen as meeting the PBL criterion of authenticity.

STUDY III, TABLE 2, P. 157

Table 2. The twelve project-based learning (PBL) units included in the case study. Description includes the country, the level of education, the StarT theme, the length of the PBL unit and the number of projects done by student groups

CASE	Country	Level of education	Number of projects	StarT theme	Length of the PBL unit
1	Lithuania	Primary school (4th grade)	1–5	Everyday mathematics	Time spent on project was spread across the school year
2	Indonesia	Lower secondary school (8th grade)	1–5	Technology around us	4 weeks
3	Greece	Lower secondary school	1–5	Programming and robotics	Not specified
4	Romania	Upper secondary school	6–10	Stars and space	Not specified
5	Portugal	Upper secondary school	6–10	Well being	From December 2016 to March 2017
6	Turkey	Upper secondary school (16-year-old)	1–5	Nature and environment	Not specified
7	Spain	Secondary school	1–5	Everyday mathematics	Not specified
8	Hungary	From early childhood education to secondary schools	1–5	Nature and environment	A week, working daily
9	Belgium	Primary school (5th grade)	1–5	Programming and robotics	Six or seven ‘sessions’ during a month
10	Finland	Primary school (5th grade) and lower secondary school	1–5	Stars and space	Time spent on project was spread across the school year
11	Finland	Lower secondary school (9th grade)	1–5	Nature and environment, Technology around us	Two or three lessons (45 minutes) per integrated subject; approximately 10 lessons
12	Lithuania	Upper secondary school	over 15	Everyday mathematics	Multiple project events organized during the school year

STUDY III, TABLE 3, P. 159

Table 3. Teachers views on the advantages of project-based learning (PBL).

Advantages of PBL	**Teachers**					
	Finnish (99)		Other (145)		All (244)	
	n	n (%)	n	n (%)	n	n (%)
Learning outcomes	62	62,6	86	59,3	148	60,7
Skills	37	37,4	43	29,7	80	32,8
Increased awareness	2	2,0	27	18,6	29	11,9
Collaboration	57	57,6	74	51,0	131	53,7
Motivation	56	56,6	41	28,3	97	39,8
Student-centred	47	47,5	44	30,3	91	37,3
Versatility for education	36	36,4	49	33,8	85	34,8

STUDY III, TABLE 4, P. 161

Table 4. Teachers' views on the challenges of implementing project-based learning (PBL).

Challenges of PBL	Teachers					
	Finnish (99)		Other (145)		All (244)	
	n	n (%)	n	n (%)	n	n (%)
Facilitating PBL	62	62,6	81	55,9	143	58,6
Time management	33	33,3	26	17,9	59	24,2
Project facilitation	30	30,3	51	35,2	81	33,2
Teachers skills	12	12,1	9	6,2	21	8,6
Structural issues						
Technical	35	35,4	16	11,0	51	20,9
Resources	26	26,3	10	6,9	36	14,8
Interactional issues						
Student-related	23	23,2	30	20,7	53	21,7
Collaboration	20	20,2	10	6,9	30	12,3

Elements of PBL	Cases												Science teaching practices related to the element
	1	2	3	4	5	6	7	8	9	10	11	12	
Learning goals	1	n/a	1	1	1	1	1	1	1	1	1	1	To apply and learn subject knowledge; to understand the relationships between phenomena; to improve thinking, communication and team-working skills; to train creativity and rigour; to improve self-esteem and motivation; to raise awareness of an issue related to the project (e.g. climate change and gender equality); to grow up to be responsible citizens.
Subject content	1	n/a	1	0	1	0	1	1	1	1	1	1	
Skills	1	n/a	n/a	1	1	1	0	1	1	0	0	1	
Centrality of the project	1	n/a	1	1	1	1	1	1	1	1	1	1	Setting project framework or steps of the process; integrating project working into subject teaching by choosing a convenient theme and allocating sufficient lesson time for projects; including versatile teaching activities to bridge theory and practice; supporting inquiry
Contextual	1	1	1	1	1	1	1	1	1	1	1	1	Teachers set a theme or a problem beforehand that can be incorporated into subject teaching; setting a common theme or problem together with students; deriving a theme or a problem from the local context; giving students freedom to choose their own driving question or a problem from a common theme.
Driving question	0	1	0	0	1	1	0	n/a	1	0	1	0	
Theme-based	1	1	1	1	1	1	1	1	1	1	1	1	
Real world	0	1	0	0	1	1	1	1	1	1	1	1	
Project artefact	1	1	1	1	1	1	1	1	1	1	1	1	Booklets, brochures, posters, written reports, crafted products with electronics, videos, quizzes, songs, workshops for younger students and exhibitions.
Collaborative learning	1	1	1	1	1	1	1	1	1	1	1	1	Whole class discussions and brainstorming, working in small groups of 3 to 5 students or in pairs, collaboration of multiple classed (same grade or different graded) and different subjects, collaboration with organizations or companies (special material, expertise), public presentation for larger audience (whole school, parents, at events).
Group work	1	1	1	1	1	1	1	1	1	1	1	1	
Interdisciplinary	1	0	1	1	0	n/a	0	1	1	1	1	1	
Other	1	0	1	1	1	1	0	1	1	1	1	1	
Constructive	1	1	1	1	1	1	1	1	0	1	1	1	Establishing the aim and tasks, gathering information by student (using schoolbooks and online resources) or given by teachers or outside experts (lectures, demonstrations, and assignments), discussing and analysing the problem (within group, with teacher and/or the whole class), students test possible solutions (building a prototype, taking measurements), writing project diaries, making mind-maps.
Investigation	1	1	1	1	1	1	1	1	0	1	0	1	
Critique and revision	0	0	0	0	0	0	0	1	0	1	0	1	
Student engagement	1	1	1	1	1	1	1	1	1	1	1	1	Group formation by teachers or students; students involvement in choosing a theme, aims, project artefact and how to work and create the artefact varied from teacher-led to autonomous group work by the students; often teachers set the frame for the project and students work autonomously inside the frame. Teachers engage students by discussions, brainstorming, activities (hands-on, games or quizzes), participating in contests and study visits.
Student-centred	0	1	1	1	1	1	0	1	0	0	1	1	
Teacher-led	1	0	1	1	1	0	1	1	1	1	1	0	
Scaffolding instruction	1	n/a	0	1	n/a	n/a	0	1	1	n/a	1	1	Diversifying learning assignments and projects, giving theory lessons related to the project topic, setting the project phases and schedule, guiding towards a source of information (books, online material, experts), providing needed resources, asking guiding questions, making it possible for students to help each other and ask questions.
Assessment	1	n/a	n/a	1	n/a	n/a	n/a	1	1	n/a	n/a	1	Students reflect on their work (what was successful, what did not work, what they learned) for example in project diaries or during presentations. Presentations, class discussion and forms are used as opportunities for peer and teacher feedback, school teachers and other experts asked to evaluate project presentations, quizzes relating to project theme, voting for best project artefacts, participating in contest
Project artefact	n/a	n/a	n/a	1	n/a	n/a	n/a	n/a	n/a	1	1	1	
Student reflection	1	n/a	n/a	1	n/a	n/a	n/a	1	1	n/a	n/a	1	
Feedback	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1	1	n/a	n/a	1	
Publicity	1	1	1	1	1	1	1	1	1	1	1	1	Organizing fairs or exhibitions (school, library, local events) with oral presentations, posters and stands to present the project and artefact, oral presentations in classroom, building a website for the project, making a short video and other online applications, writing a magazine, making a brochure.
Public presentation	1	1	1	1	1	1	1	1	1	1	1	1	
Public product	0	0	1	0	0	1	0	0	1	0	1	1	

STUDY IV

Typology or design principles	School level	Settings	Author, year
SSI education involves the use of relevant scientific topics that require students to engage in investigation, dialogue and debate. It requires teachers to change their role from an instructor to facilitator and to use authentic real-life context that supports the integration of scientific and nonscientific disciplines. SSI education should focus on topics such as students' scientific literacy, characted building, moral reasonging, decision-making and argumentation skills.		SSI education	Zeidler & Nichols, 2009
Six 'currents' in STSE education: application/design current highlights the link between science and technology, historical current highlights science as a uniquely human endeavour, logical reasoning current encourages students to think like scientist, value-centred current focuses on ethics and moral reasoning, sociocultural current emphasises science and technology as social institutions existing within a broader sociocultural context, and socio-ecojustice current shifts the focus from understanding the impacts of science and technology on society and environments on critiquing and solving these problems through human agency and action		STSE approach	Pedretti & Nazir, 2011
Investigating and Questioning our World through Science and Technology (IQWST) units are built on five key aspects of coherence: learning goal coherence; intra unit coherence between content learning goals, scientific practices, and curricular activities; interunit coherence supporting multidisciplinary; coherence between professional development and curriculum materials to support classroom enactment; and coherence between science literacy expectations and general literacy skills	Middle school science teaching	Coherent Science curriculum	Krajcik et al., 2012
The framework for SSI is composed of three core aspects; Design Elements, Learner Experiences, and Teacher Attributes which together are shaped by various contexts such as the classroom, the school, the community, and educational policies. For example, the following aspects should be taken into consideration: 1) the curriculum itself is centred on SSI, 2) teachers act as facilitators, 3) learners are provided with scaffolds to engage in higher-order thinking processes and to transfer and use knowledge in new situations, 4) learners have an opportunity to engage in scientific investigations and argumentation, and 5) the classroom environment needs to be supportive, collaborative and respectful.	Basic education	SSI education	Presley et al., 2013

Typology or design principles (continued)	School level	Settings	Author, year
To achieve what they call situated STEM learning they propose focusing on the following design principles: Scientific inquiry, technological literacy, mathematical thinking, engineering design, and community of practice		STEM education	Kelley & Knowles, 2016
In the PIRPOSAL model for integrative STEM education engineering design is central and represented as eight phases of engagement encountered by the designer when attempting to resolve an engineering challenge: problem identification, ideation, research, potential solution, optimization, solution evaluation, alterations, learned outcomes. Question posing initiates all phases in the engineering process.	K-12 science, mathematics and technology education	STEM education	Wells, 2016
Integration of art in science education can be by integration through content or activities. Content integration includes a direct link between concepts and ideas or indirect link through themes or artefacts. Integration through activity connects an activity in one domain and a concept or an artefact in the other domain with the exception of mutual activities belonging to both domains.	Secondary school science education	Art and science integration	Turkka et al., 2017
Learn STEM model comprises five key characteristics: interdisciplinary; iterative learning process; holistic; practical, and social. Model is s based on real-world problems and stimulates professional carriers in this direction which can eventually assist in solving real-world challenges of society. Through reflection and repeated training learners gain knowledge and build STEM skills and competence. Learners will use and demonstrate their obtained knowledge and skills in everyday life problems and successfully apply their developed competences in new situations.	Secondary school STEM teaching	STEM education	Stracke et al., 2019
Teachers' implementations had three common principles: teachers engaged in continual reflection while teaching, teachers and student engaged in dynamic learning transactions based on a particular task and concept covered, and learning was anchored through science projects	Middle school	Pedagogical model for integrated STEM education	Gardner & Tillerson, 2019

STUDY IV, TABLE 2

Table 2: The frequencies for participants use of integrated education and collaboration during the last two school years. Participants are divided in groups according to the education level they teach at: pre-service (i.e., teacher students), pre-primary, primary and secondary schools.

	Pre-service (n=29)	Pre-primary (n=20)	Primary school (n=28)	Secondary school (n=22)	Total (n=99)
Has used integrated education in their teaching during the last two school years					
Never	9 (31.0 %)	5 (25.0 %)	1 (3.6 %)	12 (54.5 %)	27 (27.3 %)
Once	11 (37.9 %)	3 (15.0 %)	4 (14.3 %)	1 (4.5 %)	11 (11.1 %)
2-5 times	7 (24.1 %)	7 (35.0 %)	16 (57.1 %)	8 (36.4 %)	33 (33.3 %)
At least 5 times	2 (6.9 %)	5 (25.0 %)	7 (27.7 %)	1 (4.5 %)	15 (15.1 %)
Has collaborated with other teachers during the last two school years					
Never	12 (41.4 %)	8 (40.0 %)	1 (3.6 %)	8 (36.4 %)	29 (29.3 %)
Once	6 (20.7 %)	5 (25.0 %)	3 (10.7 %)	3 (13.6 %)	17 (17.2 %)
2-5 times	7 (24.1 %)	6 (30.0 %)	9 (32.1 %)	8 (36.4 %)	30 (30.3 %)
At least 5 times	4 (13.7 %)	1 (5.0 %)	15 (53.6 %)	3 (13.6 %)	23 (23.3 %)
Has collaborated with an organization or a party beyond school during the last two school years					
Never	15 (51.7 %)	8 (40.0 %)	7 (25.0 %)	11 (50.0 %)	41 (41.4 %)
Once	6 (20.7 %)	4 (20.0 %)	4 (14.3 %)	4 (18.2 %)	18 (18.2 %)
2-5 times	7 (24.1 %)	6 (30.0 %)	7 (25.0 %)	6 (27.3 %)	26 (26.3 %)
At least 5 times	1 (3.4 %)	2 (10.0 %)	10 (35.7 %)	1 (4.5 %)	14 (14.1 %)

STUDY IV, TABLE 3

Teaching scenarios and perceptions of their integrated nature. Participants n=85..

Scenario number	Participants identifying scenario as integrated	Instructional scenario
7	98.80 %	During a unit on the solar system, the teacher asks the students to create a scale model that shows the relative size and distance between the Earth and two other planets. The students continue to work with the model in art class.
4	87.10 %	A fourth grade class is doing a project on dinosaurs. A group of students makes a chart that compares the sizes of the 5 different dinosaurs showing their metric heights and weights.
6	81.20 %	During a mathematics course the teacher discusses with the whole class about how for example geometry can be seen in art and gives examples about Fibonacci sequence and golden ratio in art.
1	70.60 %	During a chemistry class teacher instructs students in making a project about a chemical that can be found in their everyday life and find out about the safe use of the chemical.
2	67.10 %	Students in seventh grade mathematics are working on graphing data. The teacher has student pairs measure their pulse each minute for ten minutes while one student jogs in place.
5	60.00 %	In a course on acoustics, the class listens to the sounds of different instruments and tests instruments, guided by the teacher, and compares their frequencies.
3	31.80 %	Sixth grade students are studying a unit on earthquakes. The teacher asks students to find the difference between two historical earthquakes using a table involving magnitudes according to the Richter scale.
8	31.80 %	Eighth grade students are investigating crystal formation as the liquid in different solutions evaporates. Students are asked to observe and describe various characteristics of the crystals formed when the rates of evaporation, solutes used, and container shape are manipulated.

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STUDY IV, TABLE 4

Categories of the design principles of integrated science education (ISE) with frequencies (freq.) per case (n=924) and examples of coded teachers' descriptions for each category

Category	Freq.	Example
1. Comprehensive integration	535	
• Subject collaboration	393	Chemistry, safety, Finnish language all together without separate boundaries (1078) The course combines music, biology (hearing sense) and physics. (5018)
• Coherence of knowledge	102	Internal, i.e., vertical integration of the subject, i.e., the chemistry phenomena are approached from pupil's own life. Thus, from familiar phenomena towards more abstract information. (1040) Understanding the big picture and again assessing the relationship [between things] and conceptualizing scales through practice. (7059) To teach the properties of crystals and their dependencies on different variables, i.e., deepening a concept of chemistry. (8058)
• Multidisciplinary	40	Should be multidisciplinary learning experience. (3001) Brings up multiple perspectives. (1032)
2. Student engagement	168	
• Active students	87	Children can in practice implement the task (7050) The pupil undertakes his own learning process by making observations, i.e., students play an active role. (8041) Activates students' own thinking (8044)
• Student-centred approach	49	The situation is also students-centred because pupils are allowed to choose the topic and form of the project. (1010) students have to figure out [things], reflect and make decisions themselves. Acquire information, implement and find solutions. (7056)
• Meaningful to students	16	The acquired information is relevant for students' daily life. (1075) The topic is probably drawn from students own interests. (4053) [scenario is not integrated, because] jogging and measuring a pulse is not motivating for all students and then learning might not necessarily be meaningful (2039)
• Collaborative learning	16	Students cooperate. (2017) Through working in pairs, students' interaction skills develop. (2062)

STUDY IV, TABLE 4 (CONTINUED)

Categories of the design principles of integrated science education (ISE) with frequencies (freq.) per case (n=924) and examples of coded teachers' descriptions for each category

Category	Freq.	Example
3. Context-based	122	
• Link to everyday life	98	Related to students’ daily life and skills needed in daily life. (1080) Students study in detail the chemicals found at home such as cleaning products. Besides chemical knowledge one would learn about safety at home and perhaps a little about cleaning. (1050)
• Coherent context	24	This is a phenomenon familiar to everyone (2013) The theme could be earthquakes as a start for shaping a whole that combines different fields of information (3083)
4. Practical	69	
• Practical work	42	The solar system is studied in a concrete way through students' own experiments with scale models. They get to try out how the planets are related to each other. (7081) By experimenting with real instruments, comparisons of frequencies are made. (5071) A longer project (7067)
• Investigation	27	Students can concretely study some everyday phenomenon by themselves, in this case, the heart rate during a run is examined which at the end is presented as a graphic (2081) Inquiry- and observation-based experimental [work] is ISE. (8011) Investigative approach to working (5039)
5. Versatile	30	[to make the scenario integrated] you could get acquainted with the production process of a chemical and even ask a specialist to visit or make a visit to the sources of the chemical, if possible. (1055)