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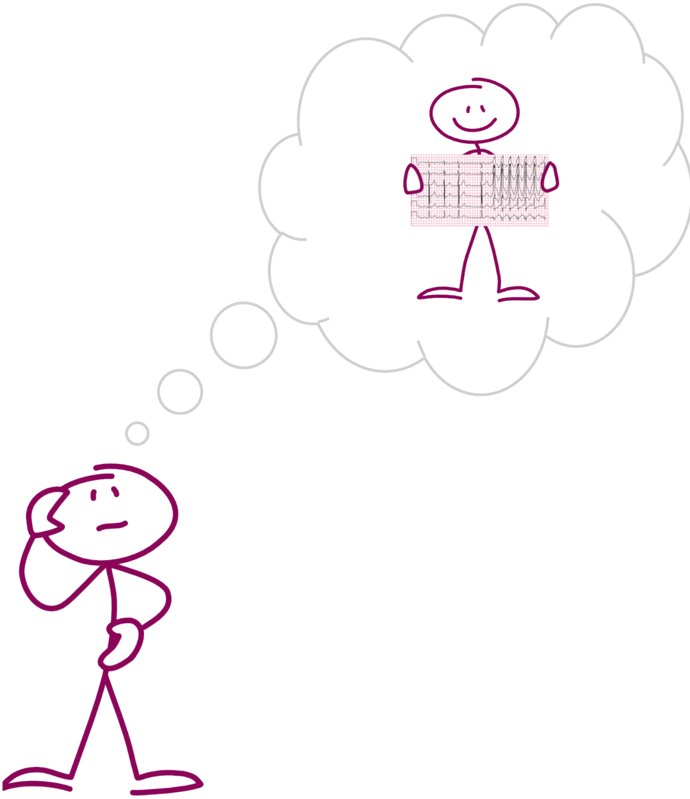
Web-based ECG education: utility and usage in undergraduate medical education



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THESIS FOR DOCTORAL DEGREE (Ph.D.)

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‘*It is through education that the daughter of a peasant can become a doctor, that the son of a mineworker can become the head of the mine, that the child of farm workers can become the president of a great nation.’*
Nelson Mandela

To my wonderful family

Juliane, Ida och Isak

ABSTRACT

Investigating the heart with an electrocardiogram (ECG) is an important, frequent and non-invasive investigation. Failure to correctly interpret the ECG may harm the patient. Learning to interpret ECGs is difficult for many medical students. Students and teachers have asked for more training, but this is difficult to provide in traditional educational settings. A web-based learning resource could be useful and this thesis aimed to explore the utility and usage of a web-based ECG resource for medical students in a blended-learning setting.

Methods and result: Study I evaluated a web-based ECG learning resource at the clinical internal medicine course in the medical programme. In a non-randomised study with an interventional arm and a control arm 62% of the students in the intervention group used the resource. The users ranked the ECG learning resource as a useful instrument to learn ECG. An optional ECG diagnostic test was performed with students from both the interventional and the control group. The mean result was better in the interventional than in the control group ($p = 0.03$). The intervention group improved learning with an effect size of 0.65 (Cohen's d^a).

Study II was a case-control study that investigated whether students´ learning styles influenced the decision to use or not to use the web-based ECG learning resource during a pre-clinical course in diagnostic methods. Fifty-five students (59%) were users of the web-based learning resource. We found no evidence to support that learning styles influenced the students´ choices to use the web-based ECG-learning resource.

Study III further explored why medical students chose to use or not to use the web-based resource in a blended-learning setting. In a mixed-methods study we explored medical students' rationales for this choice. The web-based ECG learning resource contributed to student learning based on principles of self-regulated learning, in which students made their decisions based on a multitude of factors. These factors included experiences during clinical rotations, previous study experiences and strategies for regulating learning.

Study IV investigated ECG-interpretation skills of final-year medical students. Additional assessments included attitudes toward ECG, individual skills and different methods of learning. To our knowledge, the students did not have access to the web-based resource used in the other studies of this thesis. The median test result (IQR) was 50.8% (37.6–60.0%). There was a gender difference; male students had higher average scores. Thirty-nine percent of the students stated that they were unsure of ECG interpretation. Student estimations of their ECG-interpretation skills correlated with diagnostic test scores ($r = 0.38$, $p < 0.001$) but with a gender difference: females $r = 0.48$, $p < 0.001$ and males $r = 0.035$, $p = 0.82$.

Conclusions:
Adding a web-based ECG learning resource in a blended-learning context seems to be more effective than just using traditional teaching methods.
There are few barriers to effective use of a web-based ECG learning resource in a blended-learning setting. However, not all students need supporting learning resources.
A supplementary web-based ECG learning resource contributes to student learning based on principles of self-regulated learning in which students make their decisions based on a multitude of factors.
Graduate medical students recognise the importance of ECG skills both in their present situation and in their future role as physicians. Despite this, more than one third of the students stated that they were unsure of ECG interpretation. The students' test results confirmed a lack of skills, with poor scores for ECG interpretation even in cases with life-threatening diseases.
What should be explored is how useful a web-based learning resource can be and how long-term use could enhance long-term skills. Further research is needed about how to secure enough ECG-knowledge among medical students reaching their final examination.

SAMMANFATTNING

Att undersöka hjärtat med ett elektrokardiogram (EKG) är en viktig, vanlig och icke-invasiv undersökning. En felaktig tolkning av EKG kan leda till allvarlig patientskada. Att lära sig EKG-tolkning är svårt för många läkarstudenter. Studenter och lärare önskar mer utbildning, men detta är svårt att tillhandahålla i traditionella utbildningsformer. En webbaserad inlärningsresurs kan vara användbar och denna avhandling syftade till att utforska användbarheten och användningen av en webbaserad EKG-läranderesurs för läkarstudenter i en mixad inlärningssituation med traditionellt och webbaserat lärande.

Metoder och resultat: Studie I utvärderade en webbaserad EKG-läranderesurs vid internmedicinkursen i läkarprogrammet. I en icke-randomiserad studie med en interventionsarm och en kontrollarm använde 62 % av eleverna i interventionsgruppen resursen. Användarna rankade den webbaserade EKG-lärande resursen som ett användbart instrument för att lära sig EKG. Ett valfritt EKG-diagnostiskt test utfördes med studenter från både interventions- och kontrollgruppen. Medelresultatet var bättre i interventionsgruppen jämfört med kontrollgruppen (p=0.03). Interventionsgruppen förbättrade inlärningen med en effektstorlek på 0.65 (Cohen's d^a).

Studie II var en fall-kontrollstudie som undersökte om elevernas inlärningsstilar påverkade beslutet att använda eller inte använda den webbaserade inlärningsresursen under en preklinisk kurs i diagnostiska metoder. Femtiofem studenter (59 %) var användare av den webbaserade lärande resursen. Vi hittade inget stöd för att inlärningsstilar påverkade elevernas val att använda den webbaserade EKG-inlärningsresursen.

Studie III undersökte ytterligare varför medicinstudenter valde att använda eller inte använda den webbaserade resursen i en blandad lärande miljö. I en studie med kvalitativa och kvantitativa metoder undersökte vi läkarstudenters tankegångar inför detta val. Den webbaserade EKG-inlärningsresursen bidrog till elevernas inlärning baserat på principer för själv-reglerat lärande, där eleverna fattade sina beslut baserade på en mängd faktorer. Dessa faktorer inkluderade erfarenheter under kliniska placeringar, tidigare studieupplevelser och strategier för att reglera lärande.

Studie IV undersökte EKG-tolkningsförmåga hos läkarstudenter inför deras slutexamination. Ytterligare bedömningar inkluderade attityder till EKG, uppskattning av individuella färdigheter och olika metoder för lärande. Så vitt vi vet hade studenterna inte haft tillgång till den webbaserade resursen som användes i de andra studierna i denna avhandling. Median-testresultatet (IQR) var 50.8% (37.6–60.0%). Det fanns en könsskillnad; manliga studenter hade högre genomsnittliga poäng. Trettionio procent av eleverna uppgav att de var osäkra på tolkning av EKG. Studenternas egna uppskattningar av sin EKG-tolkningsförmåga korrelerade med diagnostiska testresultat ($r = 0.38$, $p<0.001$) men med en könsskillnad: kvinnor $r = 0.48$, $p<0.001$ och män $r = 0.035$, $p = 0.82$.

Slutsatser:
Att lägga till en webbaserad EKG-läranderesurs i ett blandat lärande förefaller mer effektivt än att bara använda traditionella undervisningsmetoder.
Det finns få hinder för effektiv användning av en webbaserad EKG-läranderesurs i en blandad lärandemiljö, men alla studenter behöver inte stödet av webbaserade resurser.
En kompletterande webbaserad EKG-läranderesurs bidrar till studenternas inlärning baserat på principer för själv-reglerat lärande där eleverna fattar sina beslut baserat på en mängd faktorer.
Läkarstudenter lägger stor vikt vid färdigheter i att tolka EKG både i sin nuvarande situation och i deras framtida roll som läkare. Trots detta uppgav mer än en tredjedel av studenterna att de var osäkra på tolkning av EKG. Studenternas testresultat bekräftade bristen på färdigheter, med dåliga poäng för EKG-tolkning även i fall med livshotande sjukdomar.
Framtida studier bör undersöka hur användbar en webbaserad inlärningsresurs kan bli och hur långvarig användning kan förbättra långsiktiga färdigheter. Ytterligare forskning behövs om hur man kan säkerställa tillräckligt med EKG-kunskap hos läkarstudenter vid examen.

LIST OF SCIENTIFIC PAPERS

I

Mikael Nilsson, Gunilla Bolinder, Claes Held, Bo-Lennart Johansson, Uno Fors and Jan Östergren

Evaluation of a web-based ECG-interpretation programme for undergraduate medical students

BMC Medical Education 2008 8:25

II

Mikael Nilsson, Jan Östergren, Uno Fors, Anette Rickenlund, Lennart Jorfeldt, Kenneth Caidahl, Gunilla Bolinder

Does individual learning styles influence the choice to use a web-based ECG learning programme in a blended learning setting?

BMC Medical Education 2012 12(1):5

III

Mikael Nilsson, Uno Fors, Jan Östergren, Gunilla Bolinder, Samuel Edelbring

Why medical students choose to use or not to use a web-based electrocardiogram learning resource: mixed methods study

JMIR Med Educ 2019;5(2):e12791

IV

Mikael Nilsson, Samuel Edelbring, Uno Fors, Gunilla Bolinder, Jan Östergren

Graduating medical students lack sufficient skills despite recognizing the importance of electrocardiogram interpretation.

Submitted manuscript

LIST OF ABBREVIATIONS AND DEFINITIONS

CBME	Competency-based medical education
ECG	Electrocardiogram
ILS	Index of learning styles (learning styles)
ILS	Inventory of Learning Styles (self-regulated learning)
IQR	Interquartile range
KI	Karolinska Institutet
OSCE	Objective structured clinical examination
SRL	Self-regulated learning
TAM	Technology acceptance model
Web	Abbreviation for world wide web, i.e., a system of interlinked hypertext (text, pictures, movies) documents accessed via the internet.
Web-based ECG-learning resource	Sometimes described as a web-based programme, i.e., webpages from software that runs on a server.
eLearning	Overall terminology for web-based training, online learning or computer-based learning; computer-aided instruction.

CONTENTS

1 INTRODUCTION

Medical students meet many challenges on their way to becoming clinical physicians. The ECG examination is a powerful clinical tool (1), and medical students must learn how to interpret the results (2). Physician circumstances in everyday clinical work are not always optimal for ECG use. Stressful and time-limited working conditions make the task of interpreting ECGs difficult (3-5). Therefore, medical students require intensive ECG education while studying for their medical exam and later, during specialisation. Unfortunately, reports from both universities and healthcare systems show that there are significant challenges due to the lack of ECG-interpretation skills for both students (6) and physicians (7-9). Many clinically active physicians in emergency care and cardiology have direct experience with misinterpretation of ECG findings leading to exposing patients to unnecessary risks.

It does not appear that basic qualities of ECG education are lacking; rather, the volume and individualisation of education. The general conditions for the student learning process at the medical education programme should be good with highly motivated, education-aware medical students. For many years, digital learning opportunities have been used. The ambition of this thesis is to investigate, from a student perspective, utility and usage of adding a web-based ECG learning tool to traditional ECG education for medical students.

2 BACKGROUND

2.1 THE CLINICAL USE OF ECG

William Einthoven introduced ECGs at the beginning of the 20th century, which eventually resulted in a 1924 Nobel Prize (10). Since then, methods have improved considerably (11). In patients with varying acute symptoms, ECG changes are often an early sign of serious illness from cardiac ischaemia, life-threatening arrhythmias or metabolic disturbances (12). Other, newly-discovered diseases can also be diagnosed with ECG, such as cardiac channelopathies and sports heart disease (13, 14). It has been estimated that three million ECGs are taken each day worldwide (15). With improved treatment for myocardial infarction, malignant arrhythmias and heart failure, patient benefits because of this examination have increased further. ECG examinations are low-cost and non-invasive, making them patient-friendly (1).

As a result of technological advances, the availability of various ECG machines has increased dramatically in recent years, and ECG investigation has become available in most places in health care. Not too long ago, it was a rather exclusive investigation, and ECGs were interpreted by a few select physicians. In more recent years, all physicians come into contact with and must be able to interpret ECGs. To facilitate interpretation, many ECG machines now provide computer machine interpretation. There is a debate about the usefulness of this machine interpretation, however, and studies show a physician always needs sufficient knowledge to interpret an ECG even with the digital interpretation aid (16, 17). Incorrect computer interpretations of ECGs are seen every day in clinical work. Despite this, the digital interpretation can sometimes be a help to the physician (9).
ECG investigation can be used as a screening method in a less time-critical context, such as when a patient seeks care for fatigue or heart palpitations at a primary care facility, and this would be a low-stress environment for interpreting results. On the other hand, when the

physician is under stress, such as during an emergency or work-overload situation, great demands are placed on the responsible physician. ECG interpretation during these situations is sometimes difficult. Many impressions must be processed simultaneously, and critical decisions must be made. When it comes to ECG interpretation, some important aspects are the quality of the ECG, which can vary with interference, and time for looking up facts about the interpretation. The time for the physician to review the ECG can be short because of all the information in the room and multiple other tasks to perform.

Thus, there is a significant patient benefit for being able to quickly and correctly interpret ECGs, as well as a risk for malpractice and patient injury in the event of misinterpretation (18-20). There have been warnings from representatives of emergency medicine, internal medicine and cardiology that ECG teaching has not reached its goal of preparing medical students and physicians-in-training with the necessary ECG interpretation skills (6, 12, 18, 21, 22). There is a clear need to increase ECG interpretation education to a level that allows the individual physician to interpret ECGs in a patient-safe manner. To manage that, medical students need good learning conditions and effective tools.

2.2 ECG EDUCATION

Perspective on field learning of ECG interpretation
ECG interpretation is described as a challenge to learn and practice. Students must learn to interpret the development of the cardiac cycle over several strokes, usually measured as electrical changes in 12 standard leads. Based on standard measurements, one should be able to identify about 80 diagnoses and be able to identify the damaged location (23). This requires basic knowledge of anatomy, physiology and an unspecified volume of virtual or real patient cases (18, 24, 25).

Some diagnoses are more critical than others, usually those that are acute or cause severe injury or death unless proper treatment is immediately or urgently begun. Typically, basic ECG training takes place in three phases (see Figure 2.2_I).

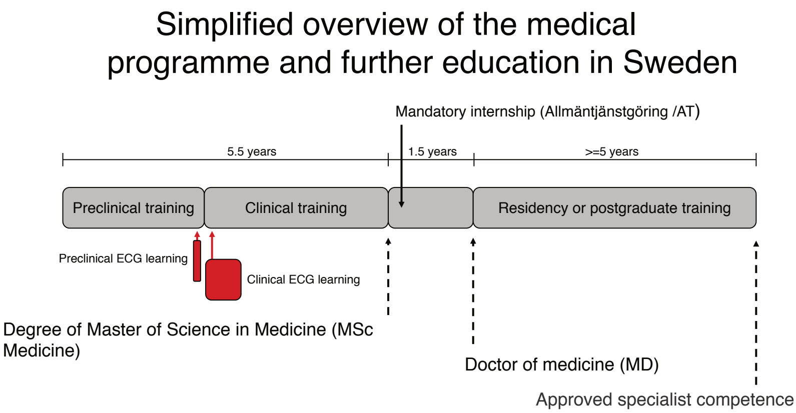

Figure 2.2_I: The timing of formal ECG education.

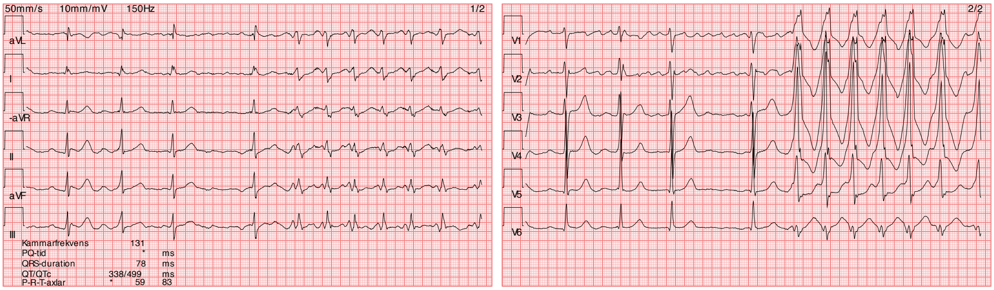

Figure 2.2_II: shows the 12-lead ECG rhythm strip. To interpret a complex ECG like this, the physician must be able to understand what is happening in the heart while making a diagnosis. Certain systematics must be available to the physician—a checklist in the head of the interpreter that assesses each lead's heartbeat. To further increase complexity, the ECG is sometimes interpreted during a rapid course of events. The physician must come up with a working diagnosis under time pressure with frequent disturbances where the ECG is just one of several examination methods. In the example above, which was done during an emergency room visit, we see a sinus rhythm that switches to pre-excited atrial fibrillation with a potentially life-threatening and very fast conduction path.

The first phase of ECG education is pre-clinical teaching, which may be part of a course on diagnostic methods. In pre-clinical education, students usually learn about the anatomy of the heart, including physiological and electrical structures. Teaching and learning are usually performed as lectures and self-studies. The students must learn typical ECG changes for common diseases. The changes in ECGs and the structure of ECG interpretation follows a checklist, and training is often performed in the context of clinical cases, usually in seminar form with a teacher. Self-studies are also needed and traditionally done through textbooks. It is typical for the pre-clinical period to end with an ECG examination.

The next phase of ECG training is the clinical phase. The students meet patients with common illnesses, and they are trained in taking medical histories, performing clinical medical examinations and developing medical reasoning followed by development of traditional internal medicine differential diagnoses, investigation plans and possible treatment. ECG teaching is central because of its value as a standard diagnostic tool. During this period, students may repeat previous lessons and have the chance to evaluate their knowledge in a clinical context. At this stage, they are given the opportunity to access what one should know as a clinical physician. The students conduct self-studies based on what they see during clinical rotation and what can possibly come up for the course assessment. The ECG assessment occurs as individual questions linked to clinical cases.

The final phase of ECG education is more informal. The initiative for this phase comes from each student. Some students have the possibility of temporary summer work as an assistant physician, or there may be a final examination during the last semester. One consideration for learning sufficiency is the time interval between the student learning to interpret ECGs during pre-clinical semesters, the beginning of the clinical semester and then the practice of ECG skills several years later. Did the student acquire sufficient knowledge for the clinical situation where this skill is needed?

Two previous studies have investigated maintained skills in connection with ECG learning. SR Bojsen et al. found in 2015 that a web-based tutorial can be an effective means of teaching ECG-interpretation skills to medical students, but the newly acquired skills are rapidly lost when the intervention is not repeated. The students lost almost half of the initially gained competence after 2–4 weeks (26). In 2016, Raupach et al. saw a similar effect with a substantial decline in performance observed over eight weeks, independent of overall performance levels (27).

Learning to interpret an ECG is complex and requires both knowledge and an ability to identify details. Training in the interpretation process is needed. The complexity of the interpretation process means that when the learners forget parts of it, they lose the process and risk failing in their interpretation.

2.3 LEARNING AND EDUCATION FOR MEDICAL STUDENTS

2.3.1 Medical education

Prerequisites for medical education
In order to understand medical education, a brief look at the present education system and how it may evolve is needed. For a long time, the medical education programme has had an overall process-based system. This traditional system has several essential features, including a hierarchical teacher-centred process, a focus on the acquisition of knowledge, sporadic subjective assessments based on comparisons with other learners, progression through training in a fixed amount of time, and a final summative assessment at the end of the training (28). One question that can be raised about the conditions for learning complex patient examination methods in the current system is whether they are adequately adapted to this learning system. Internationally, medical education has undergone several significant changes in recent decades (29). One of the changes currently in progress is the introduction of competency-based medical education (CBME) (30). CBME can be defined as education for the medical professional targeted at a required level of ability in one or more medical competencies (31). This type of education is predicated on three fundamental principles: (1) Medical education must be based on the health needs of the populations served; (2) the primary focus of education and training should be the desired outcomes for learners rather than the structure and process of the educational system; and (3) the formation of a physician should be seamless across the continuum of education, training and practice (32). Based on these three fundamental principles, the Accreditation Council for Graduate Medical Education (ACGME) and the American Board of Medical Specialties (ABMS) have endorsed six domains of core competencies: 1) Patient Care, 2) Medical Knowledge, 3) Professionalism, 4) Interpersonal and Communication Skills, 5) Practice-Based Learning and Improvement and 6) Systems-Based Practice. Medical education in Sweden is also changing. In the present reform of medical education, parliamentary document SOU 2013: 15 indicates several changes are proposed, in addition to extending medical education to six years with removal of the 18-month internship known as Allmäntjänstgöring (AT). The three recommendations are: (a) Medical education must be more clearly based on future global needs in health and medical services, i.e. hospitals and primary care units, medical research and the overall knowledge-society; (b) In order to promote student learning, the path toward the licence to practise medicine must be more extensively characterised by progression and the integration of basic sciences and clinical sciences; (c) It is crucial that the health and medical services prioritise learning and the scientific basis of their activities (33).

Competence in interpretation of the ECG
How will the learning goals and description of the necessary knowledge of ECG interpretation fit into the modernisation of medical education and CBME? Based on the overall six core competencies described above, further work on shaping the content and learning objectives have been made (34). The ability to accurately interpret ECG abnormalities can be seen as a core competency for a medical school graduate that falls within the overall learning goal of being able to understand standard diagnostic and screening tests (2). Despite this, there are currently no specific guidelines regarding ECG training and assessment (2). Conditions for student learning that provide lasting skills in ECG interpretation are limited. In the future of competency-based medical education, there is a need to raise this issue.

2.3.2 Students learning

Definition of learning
Learning has several definitions in literature (35). Knud Illeris, a scientist and professor of lifelong learning, assumes a broad definition: 'Any process that in living organisms leads to permanent capacity change and which is not solely due to biological maturation or ageing' (36). Others, such as Kolb, raise awareness of the role of experiences in and for learning. In the view of experiential learning theory, knowledge is created through the transformation of experience (37). Richard E. Mayer, who has done experimental research in the field of computer-based learning, but from the perspective of how to help people learn (i.e., the science of instruction vs. the science of learning) shares this definition.

Learning model
The Knud Illeris model of learning appeals to two different processes, an external interaction process between the student and their social, cultural or material environment and an internal psychological process for processing and acquisition (36). Furthermore, Illeris develops the model in three dimensions: content, incentive and interaction. The three angles in the figure below depict three spheres or dimensions of learning. It is these three dimensions that Illeris believes are essential for the understanding of all learning (see Figure 2.3.2_I).

The *content dimension* represents what is learned. This is usually described as knowledge and skills. But other things such as opinions, insights, attitudes, values, ways of thinking, methods and strategies can be considered learning content. Students strive to construct meaning, to attain the ability to handle the challenges of practical life and to develop overall personal functionality.

The incentive dimension provides and controls the mental energy necessary for the learning process to take place. It includes such elements as emotions, motivation and will. Its ultimate function is to secure the continuous mental balance of the student and the simultaneous development of a personal sensitivity. These two dimensions are always initiated by impulses from interaction processes and integrated into the internal operation of preparation and acquisition. Therefore, the learning content, so to speak, is always 'obsessed' with incentives at stake. For example, learning may be driven by desire, interest, necessity or compulsion; similarly, incentives are always stimulated by the content. New information can change the incentive.

The interaction dimension is social but can also be something such as a text, a picture or a film and may have several layers, ranging from the immediate situation, the local, institutional, environmental, national or even global context.

Learning always goes beyond the individual. The learning process is complex but can be broken down and understood in parts. The driving force in learning, as well as the inhibition of learning, can be seen as such a process. There are several learning models that can facilitate our understanding of ECG learning and how to investigate this.

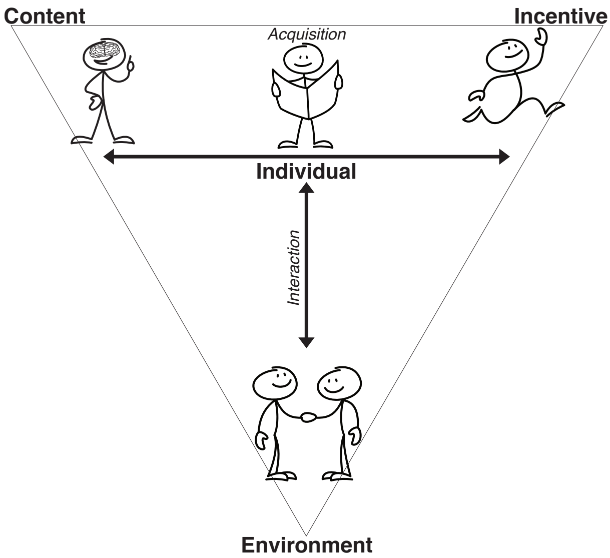

Figure 2.3.2_I: The Knud Illeris learning model shows the appeal to two different processes—an external interaction process between the student and their social, cultural or material environment and an internal psychological process for processing and acquisition.

2.3.3 Self-regulated learning

Illeris's model of learning describes that all parts, content, incentive and interaction are present together with learning and may be an advanced explanation for why students choose to use or not use web-based education instead of finding the answer in a single reason.

Definition of self-regulated learning
In the literature, there are also several definitions of self-regulated learning. Two of the most used are theories by psychologists Barry Zimmerman and Paul Pintrich (38). According to Zimmerman, self-regulation theory is structured by a few steps that include self-generated thoughts, feelings and actions that are planned and cyclically adapted to the attainment of personal goals (39) (see Figure 2.3.3_I). The theory has been linked to not only academic work, but also to non-academic performance, such as music and sports (40). According to Pintrich, self-regulated learning is defined as 'an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behaviour, guided and constrained by their goals and the contextual features in the environment'(41). Common to both theories is that the student undergoes a cycle where there is a clear goal and a plan. There is monitoring (more or less continuous), control (of the knowledge level) and a reflection reaction (what knowledge do I

have now related to the knowledge objective?) (42). According to Pintrich, self-regulated learning involves four phases that correspond to areas: cognition, motivation, behaviour and context (41).

Phase 1 (cognition) involves planning and setting goals for learning. This phase activates previous knowledge and perceptions of what to do and in what context. Phase 2 (motivation) includes monitoring how to 'meet the target' by incorporating metacognitive awareness of the self-assignment and the context. In Phase 3 (behaviour), different aspects of the self, the assignment and the context are regulated. Phase 4 (context) involves various reactive and reflective processes about the self, the assignment and the context (41). Linking areas and phases as Pintrich does, the cognitive area relates to the cognitive strategies students can use. This area involves strategic knowledge and content knowledge. The behaviour area represents the efforts made by students to seek help and continue to complete the task. This area also describes the choices that students must make to determine their behaviour. Motivational areas include motivational beliefs, task values, interests and affective reactions that the students possess about themselves and the task. Also, this area represents the strategies students apply to control and regulate motivation. The context area refers to the control and regulation of the learning environment (42).

Self-regulated learning and medical education

With the current rapid medical development, the medical profession must continuously develop its knowledge to meet the demands of patients and society at the highest possible level (44). Therefore, students need tools to be able to learn for the next exam and also to prepare themselves for future education (45).

Sandars and Cleary, in an article in *Medical Teacher*, describe how self-regulated learning theory can be applied to medical education. Cyclical control of academic and clinical performance through several vital processes include goal-directed behaviour, use of specific strategies to attain goals, and adaptation and modification of actions or strategies to optimise learning and performance (40). Although self-regulated learning has been analyzed in other areas of academic research, (45) there are relatively few articles about self-regulated learning in medical education. The number of scientific works is, however, increasing (46).

Measurement of self-regulated learning

Self-regulating skills are possible to study qualitatively or quantitatively. Several instruments are available (46). They are made up of questions and answers on a Likert scale.

The connection between academic performance and self-regulated learning

In a relatively recently published meta-analysis, Dent and Koenka found a relationship between self-regulated learning and academic achievement (47). They also discovered that the conventional way of measuring self-regulated learning may significantly underestimate its association with achievement, which is stronger for some strategies, subjects and students than others. Even in online higher education settings, a link between self-regulated learning and academic achievement is present (48). In medical education research, the link between self-regulated learning and academic achievement has been studied by Brydges et al., who found a small positive effect with supporting self-regulated learning in simulation (45). A study of medical students by Lucieer et al. found that some variations in performance could be explained by self-regulated learning skills, but a large part of the variation remained unexplained (49).

To conclude. Along with the conditions for learning based on Illeris's principles, the theories around self-regulated learning can help to understand student strategies. The importance of

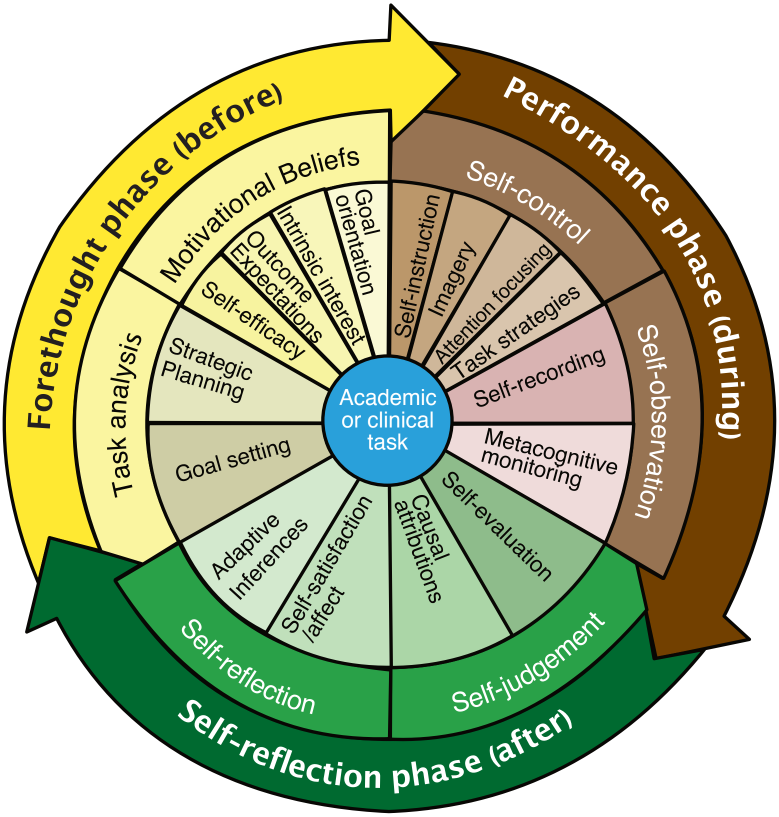

Figure 2.3.3_I: The cycle of self-regulated learning (SRL) adapted from Zimmerman by Anthony Artino and Kenneth Jones, professors of preventive medicine and biometrics (43). The three sequential phases of self-regulated learning: forethought (before), performance (during), and self-reflection (after). The model also shows, within each phase, the sub-processes of SRL. Printed with permission from Academic Medicine.

learning objectives, and how these can be matched with learning goals, are evident. Furthermore, self-regulated learning theory sheds light on the fact that these strategies can affect learning outcomes.

2.4 LEARNING STYLES

Definition of learning styles
Learning styles can be defined as characteristic preferences for alternative ways of taking in and processing information (50). The theory of learning styles is based on aptitude–treatment interaction (51), which occurs when a person with learning styles attribute 'X' learns better with instructional method '1' than with method '2'; whereas a person with learning styles attribute 'Y' learns better with instructional method '2' than with method '1'. Hall and Moseley, in a 2005 article in the *International Journal of Lifelong Education*, reviewed the theoretical bases of leading learning style models (52). They systematically described the different learning style theorists and their classification instruments (see Figure 2.4_I). An important aspect of learning styles is whether the learning styles are considered fixed or fluid. Another critical question to explore is whether learning styles are influenced by academic training.

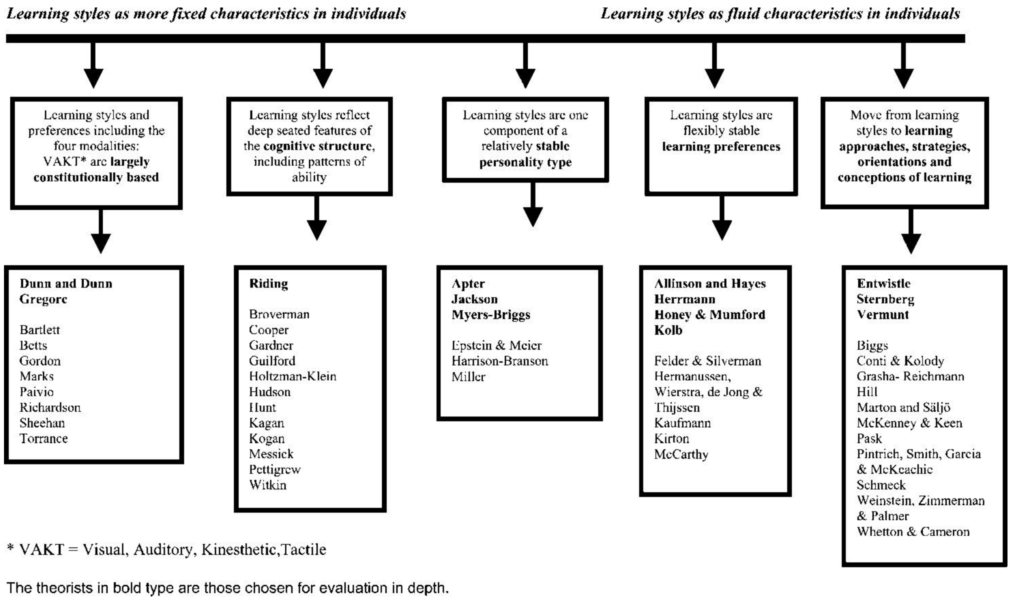

Figure 2.4_I: Families of learning styles arranged by the theorists' beliefs about whether the characteristics are fixed or fluid (52). Printed with permission.

Measurement of learning styles
Over the years, several instruments have been developed to measure learning styles (53). By measuring, it is possible to study the influence of a learning style on academic performance. There are two reasons learning styles are interesting in our research. In the years 2002 and 2005, two researchers published work about learning styles that are important for further information about learning styles in medical education. According to Ferguson et al., few studies have examined the effects of learning styles, interviews, personal statements and references in relation to achievement in medical training. These factors must be explored in future studies. Hall et al. said, 'The evidence indicates that work on learning styles is likely to

be fruitful' (47). David A. Cook also wrote in *Academic Medicine*, 'Future research could use CLS [cognitive and learning styles] theory and existing evidence to develop and test hypotheses regarding the role of learning styles in WB [web-based] instructional design.' (54). The reason learning styles are attractive from a web-based education perspective is the potential for instructional design adaptation on an individual basis. Using a learning style measurement instrument and then directing the student to the correct instructional design in order to maximise each student's learning style would be a significant educational strength.

When it comes to conditions for learning, style theories are easy to relate to intuitively. Most people can recognise their preferred learning styles, such as whether they learn better by sitting in a lecture or reading a text. Differences in learning styles could be an explanation for why students choose to use or not use a learning resource.

2.5 WEB-BASED LEARNING IN MEDICAL EDUCATION

There are many synonyms for web-based learning in existing literature, including web-based training, eLearning, online learning and computer-based learning. By definition, web-based learning in medical education can include all learning interventions that use the internet (55). The term 'computer-aided instruction' seems to have been used before faster broadband was available, and web-based learning might describe the current format more clearly. The overall concept of web-based learning also includes several perspectives. One of these perspectives is 'who': faculty, teacher or student. Rachel Ellaway, Assistant Dean for Informatics at Northern Ontario School for Medicine, has pointed out that much of the learning discussed in literature is approached from a teacher perspective rather than a student perspective (56). Another perspective of web-based education is whether the training is a stand-alone course or combined with traditional education or takes place in a blended-learning context. A final perspective is the stage of medical education for which the web-based education is intended.

Instructional design
Instructional design encompasses evidence-based principles for how to design effective instruction (57). Effective instruction will, if used correctly, create conditions for more efficient learning (58). Ruth C. Clark and Richard E. Mayer conducted a series of studies investigating principles to be considered to ensure that courseware meets human psychological learning requirements (59). Following these principles provides a significant learning effect. Many of the principles, such as the multimedia principle, apply regardless of whether the course is presented on a digital medium, in a printed book or as an audio lecture (60). It is essential to point out that there is nothing magical just because the instructions are on a digital medium. Web-based learning may contain other learning structures than types of mediated instruction to strengthen learning. In one review, Cook et al. examined online communication self-assessment questions and feedback (61). The results indicated that interactivity, practice exercises, repetition and feedback were associated with improved learning.

Availability
Web-based education has often been described as having the power of availability. Availability can be seen in several ways. One way is systemic. For example, we want to educate a large group of people but do not have resources in the form of teachers and facilities for traditional education. So, if the choice is between no education or web-based education, studies have shown a large positive effect compared with no educational intervention with pooled effect sizes of 1.00. In the same meta-analysis, Cook et al. showed educational results suggesting an effectiveness similar to traditional methods. Compared with

non-internet formats, the pooled effect size (positive numbers favouring internet) was 0.10 (62). George et al., in a 2014 article for the *Journal of Global Health*, stated that the current evidence base suggests that online eLearning is equivalent or possibly superior to traditional learning (63). A study by Vaona et al. for the Cochrane Library investigated the effects of eLearning programmes versus traditional education for licensed health professionals. They found that eLearning may make little or no difference in patient outcomes or health professional behaviours, skills or knowledge even if eLearning could be more successful than traditional learning in particular medical education settings (64). Comparative studies of eLearning versus traditional learning have been criticised repeatedly when they are confounded and do not add either educator or student information (58, 65, 66). Instead, web-based learning should relate to learning as a whole and allow students to explore different ways of modelling and understanding its constructs and trajectories (56). Another way of looking at accessibility is from the student perspective. The student can access education any number of times they choose. During a traditional lecture, the teacher covers a subject—for example, how something works. The student may not perceive the subject, but the lecture continues. In a web-based education, there is the possibility of engaging with the subject until the student has mastered it through unlimited repetition and wants to proceed. This characteristic of eLearning can lead to an increased learning effect (67).

Patient cases

Patient cases have been used in medical education and are associated with a positive education impact from both student and teacher perspectives (68). A variation of patient cases in web-based education is 'virtual patients', which are simulations of clinical cases that allow users to interact with the system and improve clinical reasoning skills (69). In a meta-analysis, positive effects were observed when training with virtual patients versus other educational models, and when blended learning was added to virtual patients as a resource. However, the effect on communication skills and ethical reasoning was lower than on clinical reasoning (69).

Blended learning

Blended learning can be defined as the combination of traditional face-to-face learning and asynchronous or synchronous eLearning. The benefits include the combination of positive web-based features with the positive sides of traditional education. The effectiveness has been investigated in medical contexts in a meta-analysis by Liu et al. The authors found blended learning was superior to no learning intervention, and the pooled effect size was 1.40 (70).

'Backside of the coin'

Web-based education that is designed correctly with a well-analysed purpose in combination with other learning has advantages, but what are the disadvantages? The cost of development, both platform and content, have been highlighted. Cojocariu et al. bring up several different weaknesses and threats, including how fragile flexibility and a high degree of learning autonomy can be. Specifically, the students do not finish tasks, and lack of social support can result in lack of motivation to complete the course. The insufficient motivation for engaging in eLearning without social support is sometimes present because students do not have enough confidence in instructional medium efficacy (71). This is confirmed in an extensive realist review article by Wong et al for *BMC Medical Education*. The authors investigated 249 reports and found that two main theories of the course-in-context, Davis's technology acceptance model and Laurillard's model of interactive dialogue, explained variations in learner satisfaction and outcomes. Learners were more likely to accept a course if it offered a perceived advantage over available non-internet alternatives, was easy to use technically and was compatible with their values and norms. 'Interactivity' led to effective learning only if learners were able to enter into a dialogue with a tutor, fellow students or as part of virtual tutorials and gain formative feedback (71).

When students study, they learn whether it is through traditional means or an electronic format such as a web-based course. How well a course uses instructional design is a factor. Another is accessibility. Blended learning seems to have an advantage over non-blended formats, even though the advantage is small. A student's choice to use or not use a specific type of education will be relevant to student perception of the knowledge or skills gained.

2.6 WEB-BASED ECG EDUCATION

Why web-based ECG education?
ECG training, regardless of the delivery format, provides educational benefits (26, 72-74). However, traditional ECG training with lectures, seminars and clinical education with supervision cannot always meet student needs to reach learning goals (75). At the same time, clinical reality does not always provide room for the clinical supervisor to discuss the findings on the ECG with the student, or the supervisor may not have enough knowledge of ECG interpretation to teach the students (15). To compensate for this, students can use self-study resources in the form of books, case descriptions on paper or web-based resources. Web-based resources can mean a lot in today's digital learning environment. The internet can provide access to a digital university library, a web-based formal course, YouTube clips, etc. These resources can create opportunities for students who need to understand a concept or learn a skill. For the ECG training, a web-based education system can provide practice opportunities and assessments (76). Furthermore, web-based resources can be continuously updated, and the teaching materials can be improved by, for example, mixed media. Books are not always available in the students' language or in the correct format (ECG can be presented in different formats inherently). Disadvantages can be seen with self-studies in ECG interpretation in relation to other ECG-training forms since it may be less effective (73). The advantage of the flexibility of web-based ECG learning can also be a disadvantage by not always providing the clarity students need (77).

How is a structured web-based ECG education designed?
Many web-based educations for learning ECG interpretation have a similar layout, consisting of either one or more comprehensive modules (see Table 2.6_II). The most common modules are: tutorial module, assessment module and ECG-interpretation module. Others have possibilities for communication, either between students or between students and teachers. There is no clear definition of what a web-based course should contain. However, for medical students, it is important that the format is correct and that the learning objective is addressed in the education. Some form of quality control should also be included. A study by Akgun, et al. found that YouTube clips related to ECG interpretation varied from useful to containing misleading content (78).

The learning effect of a web-based ECG education intervention
Several researchers have described a significant learning experience when using web-based ECG training in both a controlled environment (26, 72, 79) and in a blended-learning environment (75) (see Table 2.6_I). No study has reported the effect size of a web-based education versus no education at all. Not all studies have reported the data needed to calculate a Cohen's *d* effect size (80). If we calculate the effect size based on M1 – M2 / S (M = mean and S = standard deviation) with data from Bojsen et al. (26), the overall test scores pre-test versus post-test produce the following: (68.4-52.7)/16.8 = 0.93. This result, effect size of 0.9 is considered large (80). More education time should provide increased knowledge, but so far no study has investigated the amount of training in relation to results. In one of the most extensive studies with a web-based ECG education, a significant improvement was seen when

Table 2.6_I. Overview of studies investigating learning effects of a web-based ECG intervention for medical students and physicians.

Study	Year	Study design	Research question	Participants	Results	Conclusion
eLearning versus lecture-based courses in ECG interpretation for undergraduate medical students (68).	2014	Prospective, controlled, randomised, non-inferiority study	Compare the effectiveness of eLearning and lecture-based courses to enhance ECG-interpretation skills.	98 fifth-year medical students	eLearning was noninferior with regard to the post-course test score (15.1; 95% UCI 14.2; +∞), which can be compared with 12.5, the mean effectiveness in the lecture-based group.	A eLearning course is an effective tool for the acquisition of ECG-interpretation skills by medical students. These results should be confirmed with further multicenter studies before the implementation of eLearning courses for learning ECG-interpretation skills during medical school.
The acquisition and retention of ECG-interpretation skills after a standardised web-based ECG tutorial (20).	2015	Cohort study, web-based learning intervention	(1) the effect of a stand-alone web-based ECG tutorial on the ECG-interpretation skills, and (2) the retention of skills following the tutorial.	203 medical students	The overall mean test score improved significantly from 52.7 (SD 16.8) in the pre-test to 68.4 (SD 12.3) in the post-test ($p < 0.001$). Junior and senior students demonstrated significantly different baseline scores (45.5 vs. 57.8 points; $p < 0.001$) but showed comparable score gains (16.5 and 15.1 points, respectively; $p = 0.48$).	A stand-alone web-based ECG tutorial can be an effective means of teaching ECG-interpretation skills to medical students. The newly acquired skills are, however, rapidly lost when the intervention is not repeated.
ECG interpretation in Emergency Department (ED) residents: an update and eLearning as a resource to improve skills (15).	2015	Randomised prospective study	(1) To assess the accuracy of in the interpretation of ECGs and (2) To compare two teaching modalities that would improve ECG-interpretation skills among ED residents.	39 ED residents from four different hospitals	Significant improvement in ECG-interpretation skills (accuracy score=55%; $P = 0.0002$). However, this difference was not significant between the two groups ($P = 0.14$).	ECG interpretation was not optimal, and the eLearning programme may be an effective tool for enhancing ECG-interpretation skills among ED residents. A large study should be carried out to evaluate ECG-interpretation skills among ED residents before the implementation of ECG learning during ED residency, including eLearning strategies.
The evaluation of an open-source online training system for teaching 12 lead ECG interpretation (77).	2016	Prospective cross-sectional observations study	Evaluate the integration of a low resource ECG-training interface and a standardised curriculum for self-guided training in ECG diagnosis.	15 medical students	Accuracy scores during the training period ranged from 0–59.5% (median = 33.3%). Conversely, accuracy scores during the test ranged from 30–70% (median = 37.5%; $p < 0.05$).	CrowdLabel is shown to be a readily accessible dedicated learning platform to support ECG-interpretation competency.
Teaching crucial skills: An electrocardiogram teaching module for medical students (71).	2016	Case control study	Study improvement in ECG-interpretation skills.	101 + 90 medical students	Eighty-four percent of students (total n = 101) reported using the ECG teaching module (ECGTM); 98% of those who used it reported it was useful. Student performance and confidence were higher on the post-test. Students with access to the ECGTM (n = 101) performed significantly better than students from the previous year (n = 90) on the end-of-year ECG test.	The continuous availability of an ECGTM was associated with improved confidence and ability in ECG interpretation.
Randomised study to compare two ECG eLearning methods among medical students (78).	2017	Randomised prospective study	Compared the effectiveness of two eLearning strategies in achieving ECG-interpretation skills (C-eL and S-eL).	60 5th-year medical students	20 (77%) C-eL students and in 13 (48.1%) S-eL students, $P = 0.03$. The final score was 6.4 (5.8–7.6) in the C-eL group and 5.6 (4.2–7.2) in the S-eL group, $P = 0.04$. It correlated with the results of the theoretical test ($r = 0.42$, $P = 0.002$) and student activity during C-eL ($r = 0.4$, $P = 0.04$).	Collaborative eLearning of ECG among 5th year medical students is superior to self-eLearning.
Performance of the BMJ Learning training modules for ECG interpretation in athletes (75).	2018	Cohort study, Web-based learning intervention	Assess the performance of ECG-interpretation training modules by comparing pre- and post-online training course test results.	2023 healthcare professionals	Overall improvement of 15.3% (95% CI 13.9% to 16.6%; $p < 0.001$). The 930 who completed 4 modules were better than (18.7% increase; 95% CI 17.3 to 20.0) than those completing no additional modules (11.7% increase; 95% CI 3.3 to 17.7, $p = 0.036$).	The BMJ Learning course is a valuable first step and demonstrates that such an online tool can be effective in aiding ECG interpretation among healthcare professionals globally.

the group that completed all the parts of the course was compared to the group that only completed one part (79).

Several studies have shown a learning effect when students use a web-based ECG learning resource. However, based on these studies, we do not know much about the students' choices to use web-based education in a blended-learning environment, with the web-based system used as a supplement to existing traditional education. This could be interesting to study in a student population, where it may be important to increase performance in students with the lowest skills.

2.7 BACKGROUND SUMMARY

Learning to interpret ECGs is not easy. The interpretation process is complex to learn, and studies show that students lose significant skills within a few weeks when learning is not maintained (26, 27). Adequate learning resources are needed to prepare medical students to interpret ECGs in a patient-safe way. However, the curriculum in the medical programme is crowded and many other skills are also important to gain. At the same time, the opportunities to strengthen learning can be found with digital technology. Several studies show that digital technology can provide a learning resource at least equivalent to traditional methods. Effective learning can mean individualised learning, since individuals have different conditions and need the right support for learning. To understand ECG learning, we must understand learning from a holistic perspective. We must understand the underlying regulatory processes for learning and what potential obstacles to using digital learning resources are. Web-based ECG learning is no exception to web-based learning in general. Several studies show positive results when examining web-based ECG-learning resources. However, few studies have explored web-based ECG education from the student perspective in a blended-learning context.

Table 2.6_II: Shows the design of the intervention in studies investigating web-based ECG learning.

Study	Tutorial-module	Assessment module	ECG-interpretation module	Other
eLearning versus lecture-based courses in ECG interpretation for undergraduate medical students (68).	Five modules: 1) basic principles of ECG interpretation, 2) acute coronary syndromes, pericarditis, hypothermia, left ventricular hypertrophy, 3) tachycardia, 4) conduction system abnormalities, and 5) electrolyte disturbances.	Quizzes based on multiple-choice questions.	eLearning course contained the correct interpretations of a sample of 40 ECGs.	Two tutors were available to answer questions through a chat function.
The acquisition and retention of ECG interpretation skills after a standardised web-based ECG tutorial (20).	The tutorial included 1) a theory module about ECG and its components, sinus rhythm, causes of arrhythmias that included a detailed review of different arrhythmias and theory about heart blocks, bundle branch blocks, hypertrophy patterns, heart axis, low voltage and ischaemia.		2) A training module with the opportunity to interpret 15 different ECGs (including clinical scenarios) with feedback.	ECG for use during the training module.
ECG interpretation in Emergency Department (ED) residents: an update and eLearning as a resource to improve skills (15).	Modified from the study 'e-Learning versus lecture-based courses in ECG interpretation for undergraduate medical students.	In the quiz section, each ECG was presented with a short clinical situation. Participants chose between 4 and 5 propositions to interpret the ECG. Participants checked their answers, and a detailed feedback appeared for all the chosen answers explaining why the answer was true or false.	Generally, the eLearning course contained the correct interpretations and detailed feedbacks of 43 ECGs.	
The evaluation of an open-source online training system for teaching 12 lead ECG interpretation (77).			A total of ten cases, relevant to the training content within a given week over six weeks. Detailed feedback of the submission provided in the interface to enhance the learning experience.	
Teaching crucial skills: An electrocardiogram teaching module for medical students (71).			ECGTM of 75 cases and immediate feedback with the correct answers, allowing students to assess specific tasks.	
Randomised study to compare two ECG eLearning methods among medical students (78).			Group 1: e-mail with a full ECG case every second day. They were encouraged to analyse ECG records. Group 2: e-mail with consecutive ECG records. They were encouraged to analyse ECG records individually and answer corresponding questions within 24 hours. Afterwards they were asked to cooperate in ECG interpretation within their subgroups using an internet platform and were expected to submit agreed answers to the study coordinator within the next 24 hours. After submission of interpretations, students received comprehensive descriptions of the ECG cases .	
Performance of the BMJ Learning training modules for ECG interpretation in athletes (75).	Three educational modules to explore the particulars of ECG interpretation in athletes. The first individually focused on normal ECG findings associated with athletic training. The second and third content modules were specific to the diagnostic interpretation of cardiomyopathies and primary	To evaluate current knowledge and test any associated improvement, there were both pre-course ('identify your learning needs') and post-course ('test your knowledge') test modules.	A final module titled 'utilising standardised criteria' was added later and contained 15 stand-alone questions and difficult ECG examples intended to be completed using a summary sheet of the Seattle interpretation criteria.	

3 AIMS

The aim of this thesis is to explore the utility and usage of a web-based ECG learning resource in a blended-learning setting for medical students and thereby contribute to improved ECG education. The overall aim can be subdivided into a few questions:

- What learning effects are connected with the web-based learning resource?
- How do students value the web-based learning resource?
- What are obstacles to using the web-based learning resource from a student perspective?
- How do students reason, choosing to use or not use the web-based learning resource?
- Do graduating medical students have sufficient skills in clinically relevant ECG interpretation?

4 METHODS

4.1 DESIGN

In the first study (I) was a non-randomised controlled trial to investigate the effects of a web-based ECG resource in a blended-learning situation.

The second study (II) was a case-control study to investigate whether individual learning styles or other characteristics affected the choice to use the web-based ECG-learning resource.

The third study (III) was an exploratory mixed-method study, since there was a need to clarify the process behind usage and non-usage of the voluntary web-based resource.

The fourth study (IV) was a cross-sectional observational study of medical students during the last semester, just before graduation.

4.2 STUDY GROUPS

The studies in this thesis were performed with students at three different levels of ECG education. The first level was in the fifth semester, during pre-clinical training where students learned the basics of ECG and began interpreting the pathological ECG. The second level was during the early clinical stage in the sixth semester while attending the internal medicine course. The focus for the students in this course is not so much basic knowledge as repetition. At this stage, the students typically learn from ECGs taken from a patient that they have encountered. The students saw patients mainly in the emergency department or in an internal medicine or cardiology ward. The last level was only for repetition, since students had finished most of their clinical training at that point and were preparing for the final examination.

In Study I, we investigated medical students from the sixth semester at the Karolinska Institutet during their course in internal medicine. The students in the interventional group at the Karolinska University Hospital in Solna were offered use of the resource. Students from a corresponding course at another teaching hospital in the Stockholm area (Danderyds Hospital) without access to the web-based programme served as a control group.

In Study II, we investigated medical students at the pre-clinical course in diagnostics during their fourth and fifth semesters, where primary ECG education took place. The students studied at two teaching hospitals: Karolinska University Hospitals Solna and Huddinge. Students at both sites were offered the web-based ECG-learning programme.

In Study III, the study group consisted of sixth-semester medical students studying internal medicine at one of four teaching hospitals at Karolinska Institutet.

In Study IV, the study group consisted of medical students attending their last semester course, the eleventh semester at the medical programme at Karolinska Institutet.

Table 4.1_I: Overview of the four studies in the thesis.				
Study	**Research question**	**Design**	**Study group**	**Data analysis**
I	What learning effects are connected with the web-based learning resource? How do students value the web-based learning resource?	Non-randomised controlled trial	Medical students clinical (sixth) semester n=17+25	Student T-test, Mean Standard deviation
II	What are obstacles to using the web-based learning resource from a student perspective?	Case-control study	Medical students pre-clinical course n=91	Mann-Whitney U-test, medians and interquartile ranges, Cronbach's alpha
III	How do students reason, choosing to use or not use the web-based learning resource?	Exploratory mixed-method study	Medical students clinical (sixth) semester n=33	Qualitative data from thematic analysis dominant source for interpretation, medians and interquartile ranges, Spearman's Rho
IV	Do graduating medical students have sufficient skills in clinically relevant ECG interpretation?	Cross-sectional observational study	Medical students attending their last semester n=107	Mann-Whitney U-test, medians and interquartile ranges, Spearman's Rho, Kruskal-Wallis test

4.3 WEB-BASED ECG RESOURCE

A web-based ECG learning resource was used in three of the studies (Studies I, II and III). The web-based ECG learning resource *EKGtolkning.se* was selected for the studies because at that time it was, to our knowledge, the only available Swedish web-based education for ECG, and it was available to the research group via the author, Mikael Nilsson. The author has, together with others, developed the learning resource as a commercial project. *EKGtolkning.se* has been used for several years in a blended learning setting for physician continuing medical education. Another version of the resource is also used in an online course for nurses. For this project, the basic resource was modified with a pre-test module to suit the needs of medical education in terms of test situations. One of the authors, Bo-Lennart Johansson, reviewed the content before the students had access. The web-based ECG learning resource was designed to serve both as a complement to the standard ECG education and to be used as a 'stand-alone' tool for self-regulated learning. The resource contains all information that medical students should need during a basic ECG interpretation course (25, 83). The content is divided into four separate parts: Clinical Introduction, ECG in Detail, Pathological ECG and Clinical ECG Cases.

Clinical Introduction provides a basic explanation of the electrical activity of the heart and how this is recorded using electrocardiography. It also includes clinical symptoms, anatomy and physiology to provide a basic understanding of the placement and orientation of the heart within the chest and its relation to the ECG-electrodes. This section covers the anatomy and function of the cardiac conduction system, as well as the electrophysiological properties of the heart.

ECG in Detail covers the basic principles of ECG, and ECG recording is discussed in detail. A summary with conclusions and a thorough review of the ECG interpretation checklist is included.

Pathological ECG covers common pathological ECG anomalies. Twenty-five conditions are presented and explained.

Clinical ECG Cases consists of 70 specially selected ECGs, together with short descriptions of the clinical situations in which the ECG tracings were recorded. They exemplify several typical examples in which ECG interpretation is essential and are displayed in a Swedish ECG format.

The resource uses three pedagogical and technical solutions to implement the different parts of the course:

1) The core learning objects (see Figure 4.3_I) constitute the theoretical backbone of the course. Core learning objects are produced with text, animation and illustrations.

2) The interactive ECG-interpretation module (see Figure 4.3_II) allows students to interpret authentic ECG rhythm strips using some tools and utilities. The patient's clinical history and information about the reason for the ECGs acquisition is also provided. The module gives an opportunity to practice, apply and develop interpretation skills because the student's interpretation can be compared with an interpretation made by an expert, which will facilitate knowledge gain. The module attempts to mimic clinical reality to optimise ECG understanding and interpretation (84, 85).

3) The test system (see Figure 4.3_III) provides questions that are constructed to achieve maximal learning levels according to Blooms Taxonomy of Educational Objectives (86).

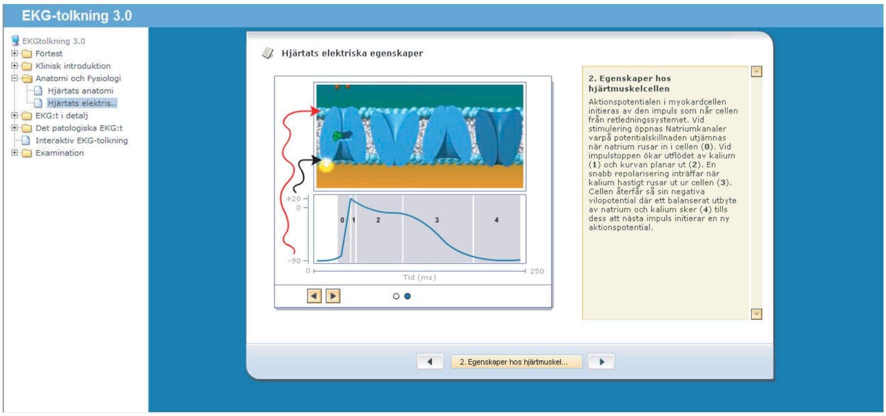

Figure 4.3_I: The depolarisation process in the myocardium shown with animation and an explanation in the text.

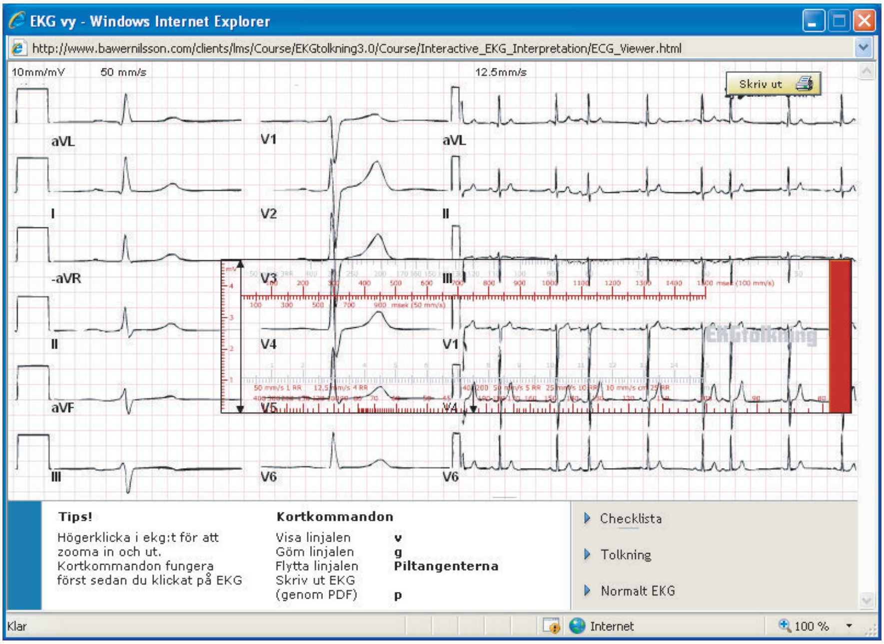

Figure 4.3_II: One of the ECG cases in the interactive ECG-interpretation module. The cases are based on clinical histories. The student is asked to interpret the ECG. One of the tools they can use for this purpose is the special moveable ruler. The ECG can be magnified together with the ruler for measuring the components of the ECG complex. The student's interpretation can be compared with that of an expert.

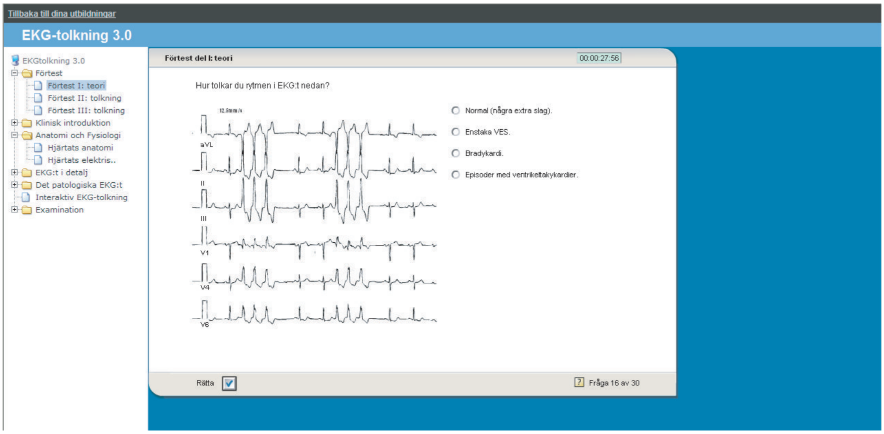

Figure 4.3_III: A test question with multiple-choice answers. Feedback in the form of the correct answer is provided after every question and after the student completes all questions in one module.

4.4 ECG TESTS

To assess student skills in ECG interpretation, tests were used in the first, third and fourth studies. All of the tests were based on ECGs and replied with short answers.

The assessment test in Study I consisted of interpretations of eight different ECGs. The ECGs were chosen from both educational sites and included background information or a clinically relevant question about findings. Otherwise the students were asked to make a structured interpretation and give a conclusion regarding the result. The examiner was blinded to students and the educational site.

In Study III, we used the Objective Structured Clinical Examination (OSCE) test (87).

The OSCE test included two ECGs representing life-threatening conditions. The final written examination contained questions covering the entire field of internal medicine.

In Study IV, the test included 10 ECG tracings accompanied by brief medical histories describing why virtual patients sought medical attention. The students were asked to interpret the ECGs in a structured way. Points were given for the right answer in the assessment of the ECG and for the correct ECG diagnoses.

4.5 INSTRUMENTS

To explore student preferences, behaviours and background characteristics, several instruments were used during the studies.

In the first study, semi-structured interviews with all students were used to evaluate perceptions of usefulness and quality of the web-based learning resources. The interview took place mid-semester. One of the authors (JÖ) asked students about their opinion of a) the general utility of web-based ECG as a learning tool and b) the quality of the specific programme used. The opinions were ranked on a 5-level graded scale.

In the second study, students attending a pre-clinical ECG course were asked at the end of the training course to complete a general questionnaire, which included questions about computer and internet usage in general, as well as a ranking of the pedagogic value of the three different learning modules of the ECG programme (learning content, self-assessment and interpretation training) on a 6-level graded scale. The questionnaire indicated future medical specialty and estimation of prior experience with eLearning.

In the third study, the students answered a questionnaire on the day of examination day. They were asked to give an estimation of their ECG-interpretation knowledge in relation to the course objectives on a scale from 0-100 and reveal their access to computers and internet.

In the fourth study, students were questioned about whether they had been employed as a junior physician (this is possible from the tenth semester in Sweden), previous professional care experience, name of training hospital, number of children in the household and what methods had been used to acquire knowledge about ECG interpretation. Students were also asked to estimate their knowledge of ECG interpretation in relation to the course objectives on a 4-level graded scale with descriptions. Students were then asked to rate influential factors for learning ECG interpretation on a 5-level graded scale.

To answer the research questions in the second and third studies, specific instruments were used. In the second study, learning styles were investigated, and several instruments were constructed to assess learning style (88). In this study, we used the index of learning styles (ILS) by Felder and Silverman (89, 90). We decided to use ILS because the instrument is relatively well studied (54, 91-93). This instrument is time-efficient with 44 questions, and it is free of charge for non-commercialised settings. Finally, studies have found the ILS to be acceptable in terms of reliability and validity (94-96). We translated the instrument into Swedish after approval from the originator. The translation was controlled by two reviewers (JÖ and UF) who translated the questions backwards from Swedish to English and compared them with the original instrument, which led to small adjustments in the Swedish version to attain congruence. Each student´s answer to the questions generated a score for each of four dimensions: active–reflective, visual–verbal, sensing–intuitive, and sequential–global. The scores in each dimension range from +11 to -11 in steps of 2. A detailed description of ILS and the four dimensions is to be found in the original article by Felder and Silverman (90).

In the third study, a different instrument was used, this time regarding study strategies from a self-regulated learning perspective. Unfortunately, the abbreviation for this instrument, inventory of learning styles, is the same as the above-mentioned ILS, so no references to this instrument will be abbreviated in this thesis.

The inventory of learning styles (97) is a more extensive instrument with different parts. We used only the second part containing questions about individual study strategies. The regulation strategy scales consist of 28 items forming three variables: self-regulated, externally regulated and lack of learning strategies. We decided to use this instrument because the scales have been successfully used in medical studies as well as in other higher education student groups (98-100). The Swedish translation of the scales was previously validated in a Swedish medical context (89), and the inventory of learning styles is described as having strengths compared to similar and different instruments since it was grounded in interview research with the target student population about learning in natural, real-life settings (101).

4.6 STATISTICAL METHODS

The statistical methods used in the four studies were adapted to the research questions, measurements and variables. Numerical data were either presented as mean and standard deviation (Study I) or medians and interquartile ranges (Studies II, III and IV) and compared either with student T-test (Study I) or the Mann-Whitney U-test (Studies II, III and IV) (102).

The Chi-square test was used to analyse categorical data (Studies II and IV). For estimation of the reliability of a psychometric test, Cronbach's alpha was analysed (Study II). Correlations were measured by Spearman's Rho (Studies III and IV). For examining the students' estimation of their knowledge in ECG interpretation in relation to their scores on the diagnostic test, the Kruskal-Wallis test was used (Study IV).

The level of statistical significance was set to $p < 0.05$. All statistical tests were two-sided. We used SPSS Inc. Released 2008. SPSS Statistics for Windows, Version 17.0. Chicago: SPSS Inc and IBM Corp. Released 2010. IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp for all analyses except Cronbach's alpha, where SAS® System 9.1 was used.

4.7 QUALITATIVE METHODS

In the third study, a mixed-method was used. To analyse the data from the student interviews, we performed the following steps. First, an interview guide was created based on pilot interviews with seven students. Second, from the group of 33 students, 15 interview participants were selected in numerical order from a course participation list. Users and non-users of the web-based ECG-learning resource were selected for interview. Adjustments were made for an equal numbers of users and non-users of the web-based programme. Seven users (four women and three men) and eight non-users (two women and six men) were interviewed by the author or a student administrator three months after the examination. The first interview was performed collaboratively with both interviewers to synchronise and make final adjustments to the interview guide.

Third, during the interview, students were asked to share thoughts and reasoning behind their choices to use or not use the web-based programme. They were also asked to share general thoughts about web-based learning and traditional media, such as textbooks and lecture notes. Furthermore, the students were asked to explain if and how they used the web-based ECG-learning programme. The semi-structured interviews were completed by telephone, recorded digitally and transcribed verbatim by a trained secretary.

Finally, the transcribed data were analysed using a thematic analysis (103).
The author (MN) and Uno Fors performed the primary analyses, which were then discussed with the other authors. Initial readings of the transcribed texts were coded and grouped according to the research question. The codes were analysed for variability, consistency and emerging patterns. The final codes were analysed iteratively.

4.8 THE RESEARCHER'S ROLE

Science can be defined as '(knowledge from) the careful study of the structure and behaviour of the physical world, especially by watching, measuring, and doing experiments, and the development of theories to describe the results of these activities'(104).

It is from this position that the author (MN), together with the research group, worked with the research questions. The author is a stakeholder in web-based education and ECG education. MN is co-founder and shareholder of a company that owns the rights to the web-based ECG-learning resource used in the studies. It is also essential to add that there is no patent on the web-based ECG-learning resource used in our studies.

Generic learning parts, i.e. content, assessment and patient cases, are put together to become a web-based ECG-learning resource. All the generic parts are possible to 'produce' with standard software. The tools used to put those generic parts together are openly described and available. In all published research articles, a declaration of conflict of interest has been made.

4.9 ETHICAL CONSIDERATIONS

In the first study, data collection was initially carried out as quality improvement work. Before publication, an ethics application was made (2006/691-31/2) for projects referencing the evaluation of web-based ECG education for students. The Regional Ethical Review Board found that the type of research for which the study was intended is not covered by the Ethics Review Act, but the board had no objections to the study. The remaining studies (Studies II, III and IV) are covered by the second ethics application (2009/245-31/4). This application was also reviewed with the same decision: evaluation of education projects such as these studies is not covered by the Ethics Review Act, but the board had no objections to the studies.

5 SUMMARY OF THE RESULTS

5.1 STUDY I: EVALUATION OF A WEB-BASED ECG-INTERPRETATION PROGRAMME FOR UNDERGRADUATE STUDENTS

Results
All students who attended the internal medicine course at the hospital where the intervention took place had access to the web-based learning resource.

Students experience the usefulness and the quality of web-based learning resources
Sixty-two percent of these students (20 of 32) tested the resource after two months. The students ranked the web-based learning resource using a five-level graded scale (from 1 = bad to 5 = very good). The mean utility rating of the web-based application for this purpose was 4.1. The mean quality rating of the ECG-learning resource was 3.9.

Acquired skills from ECG education in a blended-learning situation
An optional diagnostic test was performed by 17 students in the test group and 25 students in the control group by the end of the five-month course during the sixth semester. The maximum number of points was 16. The mean result for the students in the intervention group was 9.7 points (61%) compared with 8.1 points (51%) for the control group ($p = 0.03$), (see Figure 5.1_I). The intervention group improved learning with an effect size of 0.65 (Cohen's *d*[a]) compared to the control group. The effect size can be referred to as medium to large.

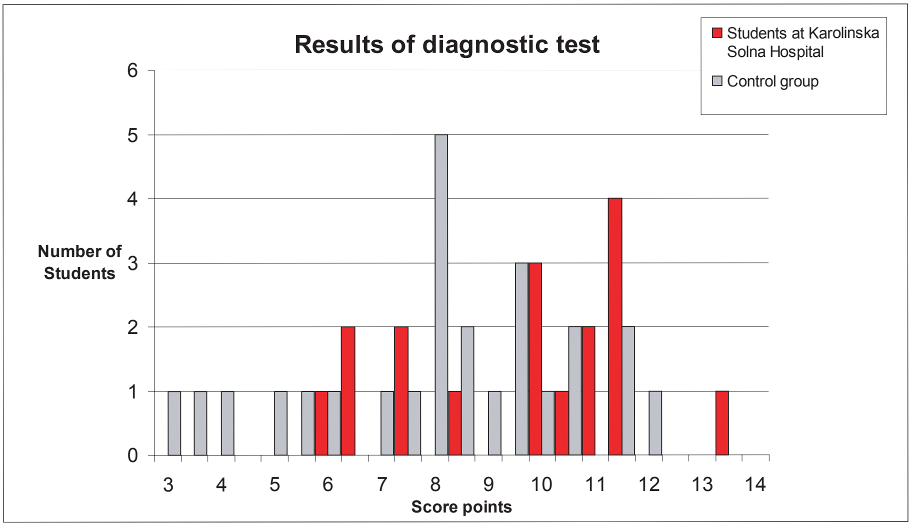

Figure 5.1_I: The student's individual scores at the diagnostic test. The test group are represented in red bars (n = 17) and in the control group in grey bars (n = 25). Maximal points were 16. The difference between the groups was statistically significant ($p = 0.03$).

5.2 STUDY II: DO INDIVIDUAL LEARNING STYLES INFLUENCE THE CHOICE TO USE A WEB-BASED ECG-LEARNING PROGRAMME IN A BLENDED-LEARNING SETTING?

Results
Ninety-three (76%) of the 123 students answered the inventory of learning styles instrument, and 91 students completed the general questionnaire. Fifty-five students (59%) were defined as users of the web-based ECG-learning resource.

Differences between users and non-users regarding learning styles and other characteristics
We found no evidence to support that student learning styles, according to the inventory of learning styles, influenced the choice to use the ECG learning resource (see Table 5.2_I). Neither did we find that gender, prior experience with eLearning or preference for future specialty contribute to differences between the groups.

Students ranked the different modules in the web-based learning resource
Students ranked the pedagogic value of the three modules on a six-level scale (from 1 = worst possible to 6 = best possible). Learning content was ranked (Mean ± SD) as 4.5 ± 1.2, self-assessment questions as 4.5 ± 1.3 and interactive ECG interpretation as 5.0 ± 1.3.

Table 5.2_I: Number and frequency of users and non users divided according to learning styles. A user was defined as a student who logged on for at least 30 minutes to the system. P values refer to Chi2 comparisons between users and non-users according to the respective dimensions. The number of responses vary because not all respondents answered all questions.

	User n	User %	Non User n	Non User %	*Chi2 p*
Total	55	59%	38	41%	
Learning styles					
Active/Reflective					*p=0.53*
Active	9	16%	9	24%	
Intermediate Act/Ref	38	69%	22	58%	
Reflective	8	15%	7	18%	
Visual/Verbal					*p=0.66*
Visual	24	44%	15	39%	
Intermediate Vis/Ver	29	53%	20	53%	
Verbal	2	4%	3	8%	
Sensing/Intuitive					*p=0.96*
Sensing	23	42%	15	39%	
Intermediate Sen/Int	27	49%	19	50%	
Intuitive	5	9%	4	11%	
Sequential/Global					
Sequential	10	18%	8	21%	*p=0.86*
Intermediate Seq/Glo	31	56%	22	58%	
Global	14	25%	8	21%	
Prior experience to E-learning					*p=0.30*
Yes	44	81%	26	72%	
No	10	19%	10	28%	
Future most interesting speciality					*p=0.17*
Internal/Family med	12	34%	4	15%	
Operating	16	46%	12	46%	
Indecisive	7	20%	10	39%	

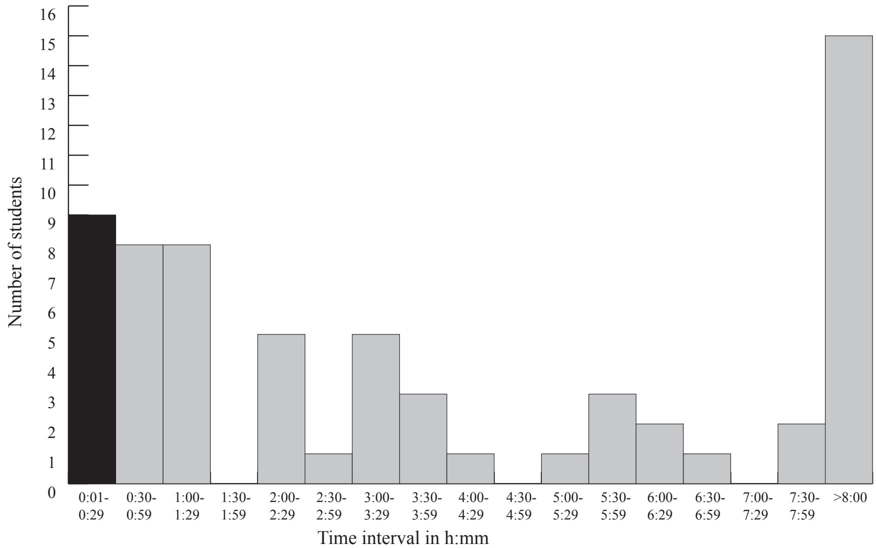

Figure 5.2_I: The number of students who logged into the programme and the time using it. Students who logged in but not met the definition of a user (30 min or more) are marked in black.

5.3 STUDY III: WHY MEDICAL STUDENTS CHOOSE TO USE OR NOT USE A WEB-BASED ELECTROCARDIOGRAM LEARNING RESOURCE: MIXED-METHODS STUDY

Flowchart methods

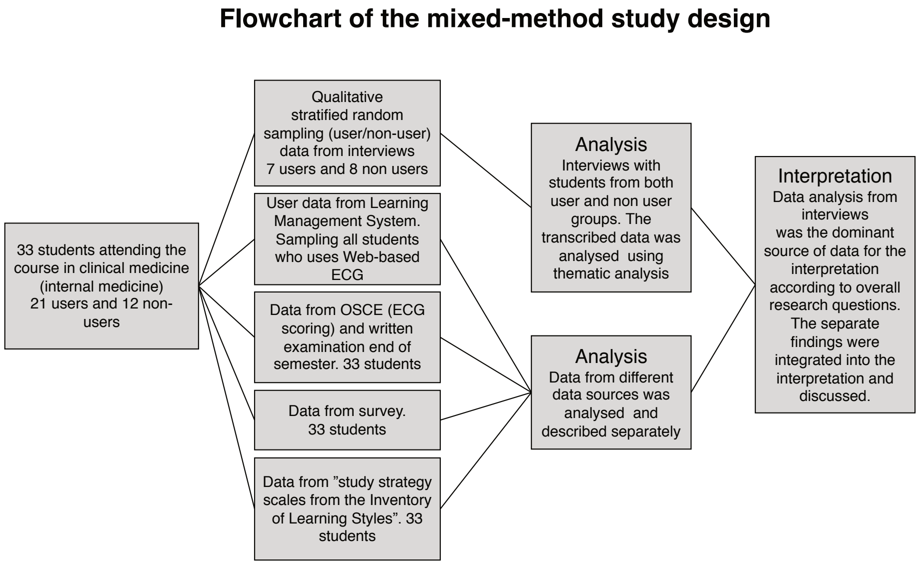

Figure 5.3_I: Flowchart of the study design in Study III.

Results
The interviews
Fifteen students were interviewed (seven users, eight non-users). In the thematic analysis, two overarching themes were identified: assessment of learning needs and planning according to learning goals. Figure 5.3_II describes the thematic map of the interview results.

Assessment of learning needs
All students thought ECG interpretation was important in their future roles as physicians. They also identified ECG interpretation as a learning objective for the ongoing course in internal medicine as well as of the OSCE and written examinations. Assessment of learning needs was a consistent theme for the majority of students and sometimes manifested as an intuitive feeling, but more often it was shown to be a conscious process involving concrete interaction with practical experience from other persons or self-control. Most of the students described the assessment of learning needs as a recurrent theme involving the other central theme, planning according to learning goals. Assessment of learning needs was associated with two sub-themes: information and control.

Planning according to learning goals
Planning according to learning goals was another consistent theme. The students talked about it as a conscious process in interaction with the other central theme, assessment of learning needs. Planning according to learning goals is associated with two sub-themes: time and control. Other associations the students mentioned were information and motivation.

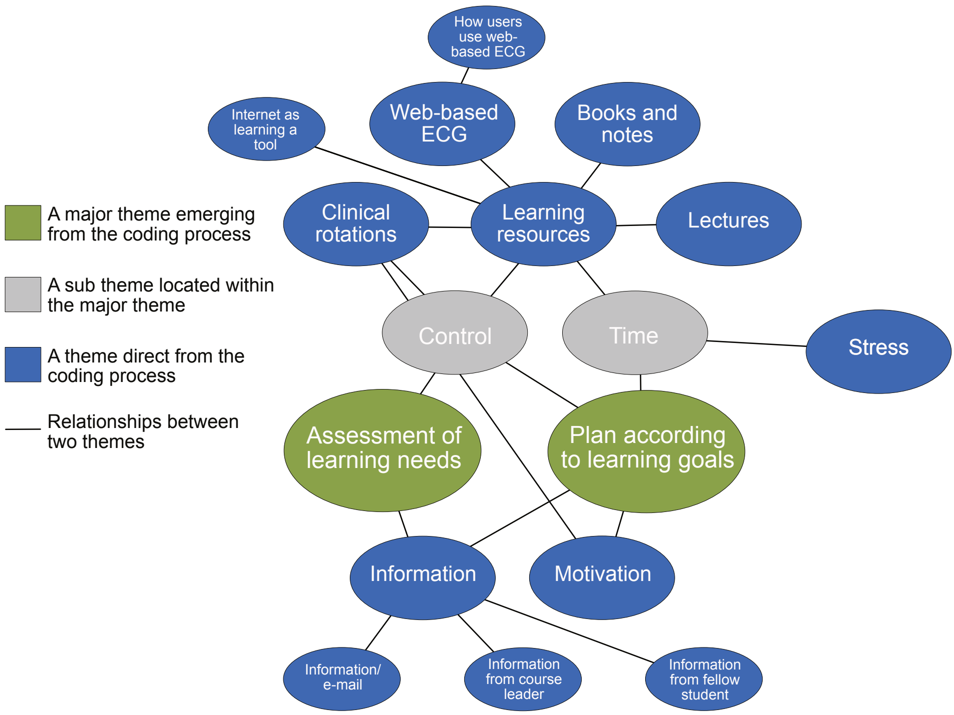

Figure 5.3_II: Thematic map showing themes and their relationships after interview analysis. Blue fields represent themes derived directly from the interviews and connect either to other 'blue' themes or straight to an overall perspective. Two essential themes, assessment of learning needs and planning according to learning goals, are key factors affecting the decision to use or not use the web-based learning resource.

The students described the curriculum as extensive, and they needed to plan their study times. When some students analysed their learning needs, they described a knowledge decline in ECG interpretation from their previous course in clinical diagnostics. This decline in knowledge was reported as a reason for requiring repetition. Some students had a longer pause in their studies than others for various reasons (e.g., maternity leave), which further increased the need for repetition.

The non-users also recognised the need for repetition, but some students had a resistance to the 'new' learning resource. This sometimes involved a negative attitude to computer-based training and sometimes simply comfort with traditional study notes.

How users use the web-based learning resource
There were different strategies and usage patterns in how students used the web-based resource. Sometimes the strategy changed because, for example, lack of time. Some students used the resource together with a study friend interpreting ECGs. The logs from the learning platform confirmed various study patterns (see Figure 5.3_III)

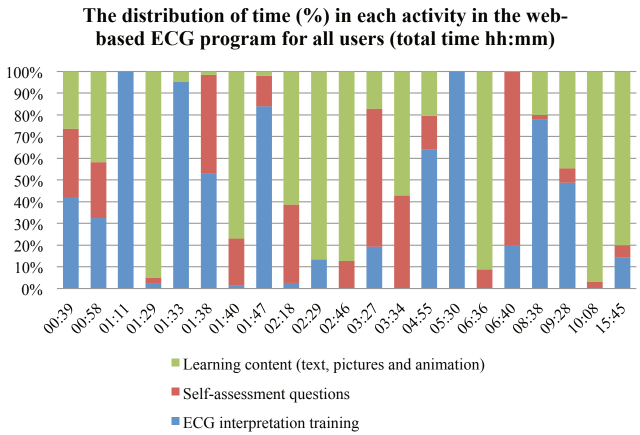

Figure 5.3_III: User distribution times in each of the three activities of the web-based ECG-learning resource. Each bar represents one student. Total time = hh:mm. During interviews, the students described different approaches to the learning resource. The common theme is that the approach is based on perceived needs.

Questionnaire and quantitative data

All 33 students, 16 women (48%) and 17 men (52%), participated in the survey and completed the OSCE and final integrated examination. They all had access to a broadband internet connection and were able to use the web-based resource if they wished to.

Twenty-one of the students (64%) were classified as users (>30 min of usage). The median time that users logged onto the system was 2:46 (h:mm, IQR 1:28 to 6:37). Women comprised 57%, compared to 33% women in the non-user groups.

The user and non-user groups were similar regarding their results for the ECG question at the OSCE station and the final examination (see Table 5.3_I). Self-estimated knowledge of ECG interpretation and learning strategy was also similar between groups.

Twelve students were determined to be minor users (median time 1:34, IQR 0:47 to 2:17) and nine students were major users (median time 6:38, IQR 5:12 to 9:21), (see Table 5.3_II). The major-user group included eight females and one male. There was a difference in performance on the ECG test in the OSCE (median females 18.0 p IQR 16.0-18.8; median males 16 p IQR 14.5-16.5, $p < 0.001$). The gender difference was not seen in the final integrated examination (females median 74.5 IQR 69.2-80.9; males median 74.0 IQR 68.8-77.5, $p = 0.68$).

Table 5.3_III shows results relating to ECG results in OSCE, activity in the web-based ECG-learning resource and strategy scales from the inventory of learning styles. No correlation was seen between the OSCE result and activity time in the web-based ECG resource. We tested for association between the regulation strategy scales (self-regulated, external regulated or lack of learning strategies). There was a correlation between OSCE results and self-regulation ($r_s = 0.37$, $p = 0.03$), as well as a negative correlation between OSCE results and lack of regulation ($r_s = -0.56$, $p = 0.004$). No correlation was seen between OSCE results and external regulation. There was no correlation between regulation strategy scales and time in interactive ECG interpretation.

Table 5.3_I: Student characteristics, self-ratings, scores in the electrocardiogram (ECG) Objective Structured Clinical Examination (OSCE), final general examination scores, and results from strategy scales from the Inventory of Learning Styles.			
	User n (%)		Non-user n (%)
Total students	21 (64%)		12 (36%)
Female gender	12 (75%)		4 (25%)
Male	9 (53%)		8 (47%)
Total activity in web-based ECG learning resource time (h:mm) **Median**	2:46		
OSCE ECG test **Median Points**	16 p		16 p
Final General Examination **Median points**	74.5 p		71.8 p
Students estimated their knowledge of ECG interpretation as 0-100% of the course objectives **Median**	80 %		80 %
Self-regulation scale **Median**	3		3
External regulation Median	3		3
Lack of regulation **Median**	2		2

Our findings, along with the qualitative and quantitative data suggest a pattern driven by student incentives in a self-regulated learning process. The analysis of the interviews highlighted different aspects behind student decisions about to what extent and how they used or did not use the web-based training resource.

The students planned their learning or decided what resources they should use for acquiring new or refreshing skills in ECG interpretation using two overarching questions to regulate their use of the available resource. First, what is my current level of knowledge? Second, what learning outcomes must I achieve?

Table 5.3_II: Student characteristics, self-ratings, activity in Web-based electrocardiogram (ECG) learning resource, and results from strategy scales from the Inventory of Learning Styles.

	Minor user n (%) (30min-2:46 h)		Major user n (%) (>2:46 h)
Total students	12 (57%)		9 (43%)
Female gender	4 (33%)		8 (67%)
Male	8 (89%)		1 (11%)
Total activity in web-based ECG learning resource time (h:mm) Median	1:38		6:38
OSCE ECG test Median Points	16 p		18 p
Final General Examination Median points	74.5 p		74.5 p
Students estimate their knowledge of ECG interpretation 0-100% of course objectives Median	80 %		85 %
Self-regulation Median	3		3
External regulation Median	3		3
Lack of regulation Median	2		2

Table 5.3_III: Results from the Spearman rank-order correlation between electrocardiogram result in Objective Structured Clinical Examination, activity in Web-based electrocardiogram learning resource, and strategy scales from the Inventory of Learning Styles.

[a]Statistical significance P<.05.

	Spearman's Rho	P Value
OSCE Result & Total activity in web-based ECG learning resource	0.14	$p = 0.52$
OSCE Result & Time in interactive ECG interpretation	0.29	$p = 0.20$
OSCE Result & Self-regulation	0.37	$p = 0.03^{a}$
OSCE Result & External regulation	0.1	$p = 0.58$
OSCE Result & Lack of regulation	-0.56	$p < 0.001^{a}$
Time in interactive ECG interpretation & Self-regulation	-0.11	$p = 0.64$
Time in interactive ECG interpretation & External regulation	-0.06	$p = 0.8$
Time in interactive ECG interpretation & Lack of regulation	-0.20	$p = 0.36$

Students had previous experiences from clinical rotations, old lecture notes and more recent lectures during the course. This gave them a sense of their level of ECG-interpretation skills. Clinical rotations seemed to be an important opportunity for students to discover their actual levels of knowledge in a clinical setting. Based on their experience, the students used accessible learning resources in an effort to reach their learning goals. The majority of students had positive views about web-based education in general as an on-demand resource. During the interviews, the students mentioned that quality measures and factors that contributed to the decision to use the web-based learning resource were other students who had used the resource or teachers who had spoken positively about the web-based resource.

We found that a theme of control was related to the assessment of the student's knowledge and skills, as well as their planning.

In conclusion, rationales for choosing to use a web-based ECG-learning resource in a blended-learning setting were complex. The analyses pointed toward principles of self-regulated learning (self-generated thoughts, feelings and actions that were planned and cyclically adapted to the attainment of personal goals) in which students made their decisions based on a multitude of factors. These factors included experiences during clinical rotations, previous study experiences, and strategies for regulating learning. An overarching aspect of resource usage in relation to individual learning goals and the need to pass the examination was the judgement of whether there was a need for a web-based resource to achieve their learning goals.

5.4 STUDY IV: GRADUATING MEDICAL STUDENTS LACK SUFFICIENT SKILLS DESPITE RECOGNISING THE IMPORTANCE OF ELECTROCARDIOGRAM INTERPRETATION

Results
We invited 129 medical students from all four study sites at the Karolinska Institutet (KI) attending the last (11th) semester of their education to participate in an assessment test and survey. To our knowledge, the students had not been offered the web-based ECG resource used in the other studies. One hundred seven of the students (83%) volunteered to participate in the study.

Assessment of ECG skills and student estimation of skills
The students' median test result (IQR) was 50.8% (37.6–60.0%) (see Figure 5.4_I). There was a gender difference between males and females ($p = 0.013$), and male students had a higher average score. However, there was no significant difference in the scores of male and female students in terms of the number of correct ECG diagnoses (maximum: 10 points). Thirty-nine percent of the students stated that they were unsure of ECG interpretation. Fifty-six students (52%) indicated that they felt reasonably confident in their ECG interpretations and only 7% of the students felt confident enough to interpret an ECG independently. Several life-threatening diagnoses had a too-low proportion of correct answers.

Another important finding was that student estimations of their ECG-interpretation skills correlated with diagnostic test scores ($r = 0.38$, $P < 0.001$) but with a gender difference; females ($r = 0.48$, $P < 0.001$) and males ($r = 0.035$, $P = 0.82$).

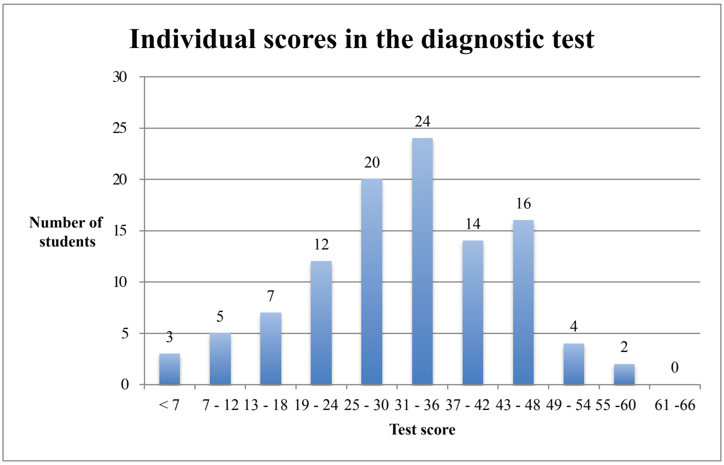

Figure 5.4_I: The students individual scores in the diagnostic test

Student attitudes toward ECG skills
The vast majority of the students (94%) stated that excellent ECG-interpretation skills were important. Seminars and self-studies were preferred by students for learning ECG interpretation (see Table 5.4_IIa). Eighty-two percent of the students indicated that good ECG

skills depended on how ECG interpretation was taught and course design. Similar results were obtained for self-study, with the majority of students agreeing that good ECG skills depended on ECG self-study. The findings indicate the student perspective that both education courses and support for self-study are important for improvement in ECG education.

The students thought both education courses and self-study were important for learning ECG interpretation, but their preferred way of learning was teacher-led methods, such as seminars.

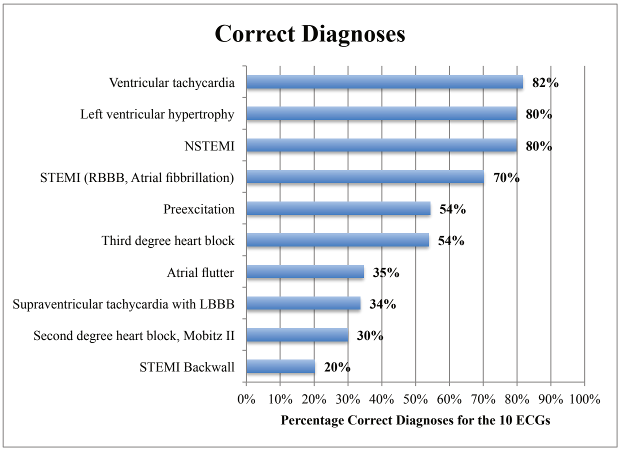

Figure 5.4_II: Performance of the students in the ECG test according to the diagnosis. The proportion of students who made the correct diagnosis based on the 10 ECG tracings. NSTEMI = non-ST segment elevation myocardial infarction; STEMI = ST segment elevation myocardial infarction; RBBB = right bundle branch block; LBBB = left bundle branch block.

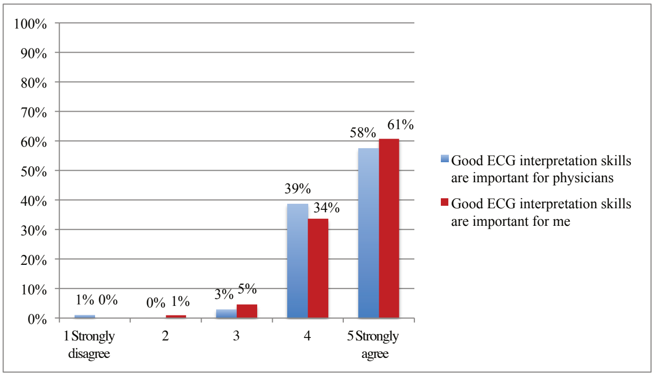

Figure 5.4_III: Students’ opinions on the importance of good ECG interpretation skills.

Table 5.4_I: Student estimation of their knowledge of ECG interpretation and the diagnostic test scores.												
Student estimation of their knowledge	**Uncertain of basic ECG interpretation (1)**			**Fairly confident in basic ECG interpretation (2)**			**Confident in independent in basic ECG interpretation (3)**			**Confident enough to teach basic ECG interpretation (4)**		
	All	Female	Male	All	Female	Male	All	Female	Male	All	Female	Male
Number of students (%)	42 (39%)	29 (49%)	13 (27%)	56 (52%)	28 (47%)	28 (58%)	8 (7%)	2 (3%)	6 (12%)	1 (1%)	0 (0%)	1 (100%)
Student diagnostic test score												
Median	28.5	28	36.5	35.2	34.2	36.2	38.5	48	36.5	33	*	33
IQR	18.5–33.8	17.5–31	19.1–45.2	25.6–43.4	25.8–39.6	25.6–44.2	35.6–44.5	45.5–48	34.5–40.4	*	*	*

Table 5.4_IIa Students' rankings of the benefit of different methods of learning how to read an ECG.

	1 not useful	**2**	**3**	**4**	**5 very useful**	**Number of students**
Lectures	2%	22%	31%	31%	14%	106
ECG interpretation training during a clinical rotation with a supervisor	9%	36%	22%	26%	6%	96
Seminars	0%	2%	12%	35%	51%	103
Self-study, books	3%	11%	25%	40%	21%	102
Self-study, Internet	4%	14%	33%	25%	24%	79

Table 5.4_IIb Post hoc analysis with Wilcoxon's signed-rank tests.

	Lectures	**ECG training during a clinical rotation with a supervisor**	**Seminars**	**Self-study, books**	**Self-study, Internet**
Lectures	*	**P<0.001**	**P<0.001**	P=0.14	P=0.22
ECG training during a clinical rotation with a supervisor	**P<0.001**	*	**P<0.001**	**P<0.001**	P=0.02
Seminars	**P<0.001**	**P<0.001**	*	**P<0.001**	**P<0.001**
Self-study, books	P=0.014	**P<0.001**	**P<0.001**	*	P=0.57
Self-study, Internet	P=0.22	P=0.02	**P<0.001**	P=0.57	*

6 GENERAL DISCUSSION

6.1 MAIN FINDINGS FROM EMPIRICAL STUDIES

6.1.1 Use and valuation of a web-based ECG-learning resource

Basic ECG training for medical students at KI takes place in three phases. The pre-clinical phase, the clinical phase and the more informal final phase.

We investigated student interactions with and opinions about a web-based ECG learning resource in the first and second phases. When offered, about 60% of students chose to use a voluntary study opportunity with a web-based ECG learning resource in a blended-learning environment (Studies I, II and III). This is a somewhat lower usage rate than was found in a study published in 2016 in the *Journal of Electrocardiology* by Chudgar et al., who found that 84% of the students during an eight-week core internal medicine clerkship used a web-based resource (75). In Studies I and II, the students had positive opinions about the web-based learning resource from the perspectives of usefulness, quality and pedagogic value. This result is in line with other such studies. Montassier et al. randomised medical students to eLearning versus a lecture-based course in ECG. Both groups were asked to rate two alternatives on a 10-point scale on which higher points were better. The web-based course received a median score for usefulness, and general interest score of 7.5 (IQR 7–8) compared to 7 (IQR 6–8) ($p = 0.03$) for the traditional course (72). Usability scores were also examined. Breen et al. had slightly lower results for student experience when using ECG training interface 6 (IQR = 3.5 on a 10-point scale). All students indicated that the learning resource improved their competency levels in interpreting ECGs (81). Chudgar et al. reported similar student answers (75). In Study IV, we asked students to express how important an ECG course was and how important self-study was for learning about ECG interpretation. Students emphasised that self-study and course structure were equally important for gaining knowledge.

6.1.2 How do students choose to use or not use the web-based learning resource, and are there obstacles to using it?

Learning styles
An important issue concerning the use of a learning resource is whether there are cognitive barriers as described in the above introduction to Chapter 2.4: Learning Styles, such as when a person with learning styles attribute ‘X’ learns better with instructional method ‘1’ than with method‘2’. In contrast, a person with learning styles attribute ‘Y’ may learn better with instructional method ‘2’ rather than method ‘1’. Learning styles and their impact on learning results have been considered by others (54, 105, 106)**.** In our Study II, however, learning styles did not affect the use of web-based learning resource. This is in line with results from a review of learning styles and computer-assisted instruction in *Health Professions Education* by Cook. He found that, of 16 studies identified, only one analysis showed an interaction between learning styles and instructional approach (107).

This inconsistency in the research could depend on several factors. According to Tangen, it could be a lack of clarity, meaning that learning styles have a lack of clarity in definitions, models and directions for implementation. Lack of robust psychometrics is another possibility, such that the psychometrics of some instruments have proven either weak or nonexistent in some cases. Lack of consideration of other variables is another possible factor, meaning that learning styles may be used as a simple solution and other essential variables, such as the influence of the learning environment or context of the learning environment, are disregarded (108). In conclusion learning styles did not seem to influence the decision to use or not use the web-based ECG learning resource.

The incentives to learn ECG interpretation
Illeris's learning model suggests that learning will always involve three different perspectives: environment, content and incentive (36). The incentive part includes the drive, which often can be attributed to motivation. So, from this point of view, motivation becomes a question. Are there differences in student motivation? In Study III, students expressed that ECG knowledge was important to them. That finding was confirmed in Study IV, where almost all students considered ECG interpretation skills important personally and for their medical roles as physicians. The goal of becoming a physician creates good conditions for student motivation (Study IV) (109). However, despite this, too few students have adequate knowledge about the ECG at the end of their education (Study IV) (6, 22, 110, 111). This indicates that motivational drive is not always enough to achieve learning goals.

How do students choose to use or not use a web-based learning resource?
Study III was conducted to explore student reasoning behind choosing to use or not use the web-based ECG resource. We found a complex picture that governs student choice in this respect. In the complex context of the decision-making process, there is also an element of a cyclical process. This process has similarities to the self-regulated learning models (see Figure 6.1.2_I) (40).

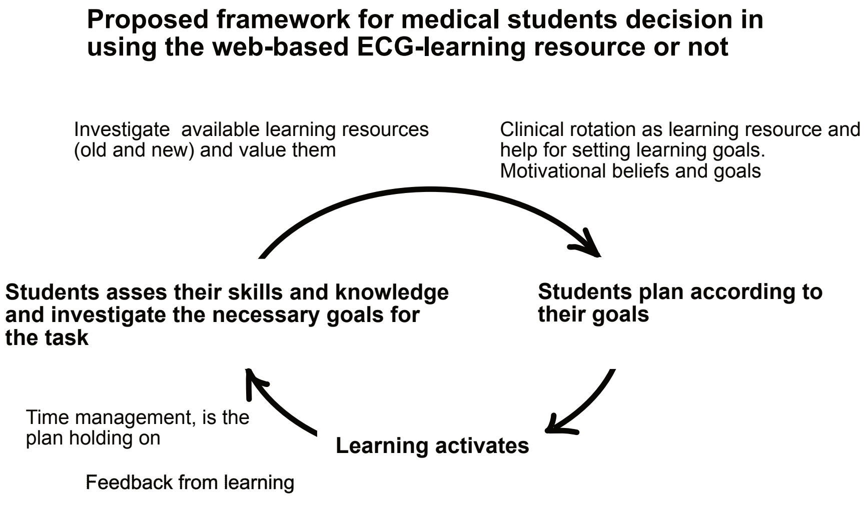

Figure 6.1.2_I: Proposed framework for how students decide to use or not use a web-based learning resource. The circle begins from the left, where students become aware of a learning goal. From this point, they assess where they are and where they must go. After this, they must investigate how they can get there (what learning resources do I have?). The students use social and other sources to determine how others have solved the learning task. Learning goals may also be influenced by sources who practise using desirable skills. The students then must learn the required skills according to the plan. They later assess their knowledge. Is the plan being maintained over time? Over time, learning goals may be adjusted.

This picture may provide a framework for understanding a medical student's decision whether or not to use a web-based ECG-learning resource. The students describe an assessment of their competence in relation to goals. This evaluation takes place continuously over the appropriate time, i.e., until the course examination. The impressions, as part of their decision-making process, come from their own and other students' levels of knowledge and ideas. The students listen to friends and others who have passed the course or other students currently in the class, and interact with tests or questions from supervisors and teachers. The overall goal is to pass the exam, which means that even if the level of knowledge is not 'right' based on the target picture, the student may need to focus on passing the course examination without getting full knowledge. The time pressure and competence development can effect a change of strategy, or it may be that students adjust their knowledge goals to 'good enough' for other reasons.

The understanding of self-regulated learning among medical students has increased (46). There are also demonstrated links between self-regulated learning and blended learning. A recent study by Stijn Van Laer and Jan Elen advocates for an instrumentalised framework that can be used to describe and thus characterise support for student self-regulation in blended-learning environments. They argue that their framework can serve as a basis for investigations and empirical trials to uncover effective designs and guidelines (112). The framework consists of seven different attributes measurable with the Likert scale: authenticity, personalisation, learner control, scaffolding, interaction, reflection and calibration. A blended-learning course could then be measured from the student's perspective using this instrument. Kassab et al. have demonstrated complex interactions in blended learning linked to self-regulated learning. In their 2015 study, a path analysis was conducted to examine the relationship between factors measuring blended learning experience, self-regulated learning and academic achievement of medical students. The findings demonstrated the effect of teaching quality and appropriate workloads on students' motivational aspects of self-regulation, specifically the expectancy and value components. Thus, students who perceived a high quality of teaching had high beliefs that outcomes were contingent their own efforts rather than external factors (they demonstrated a high control of learning). The students were more motivated to learn for internal reasons, such as curiosity or mastering the content (high intrinsic goal orientation) (113).

Other models used to describe student usage of technical learning resources
Several studies have examined students in different fields and levels of education regarding their use of web-based instruction in a single-mode context and a blended-learning context. The perspective has often had a more technical focus on the most common interactions between human and technological factors that have an effect on student satisfaction (114-116). One of the models that appears frequently is the technology acceptance model (TAM) (117, 118) (see Figure 6.1.2_II). Wong et al. found support for the TAM model while examining internet-based medical education (116). At the same time, the technology, the quality and the educational uses have changed since the article was published in 2010. A recent article by Briz-Ponce et al. regarding the use of mobile device apps in the medical curriculum found that TAM explained 46.7% of behavioural intentions to use mobile devices or apps for learning (119). Others, such as Manuela Aparicio et al., have observed cultural differences around how students approach teaching via electronic devices according to the TAM (120).
To summarise, there are no direct contradictions between the models described above which, to some extent, express different perspectives on learning and education.

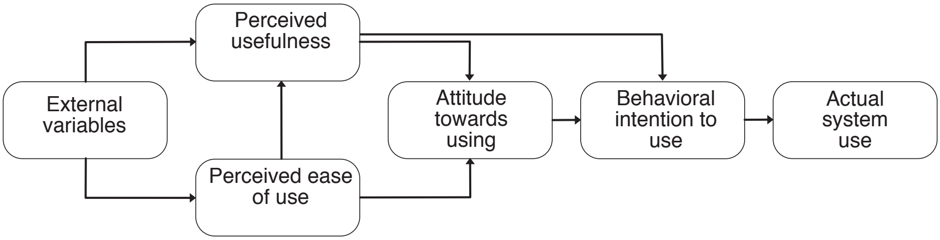

Figure 6.1.2_II: Flowchart of TAM that claims acceptance of a new information system can be predicted based on behavioural intention, attitudes toward the use of a new information system and two other internal beliefs: perceived usefulness and perceived ease of use. The definition of perceived usefulness can be 'the prospective user's subjective probability that using a specific application system will increase his or her job performance within an organisational context'. The definition of perceived ease of use is 'the degree to which the prospective user expects the target system to be free of effort.'(117, 118).

Limitations about the proposed framework

The framework for understanding medical students' decision-making about using a web-based ECG-learning resource may have limitations due to generalisability. The learning environment of medical students is associated with sometimes stressful conditions (121, 122). This is due to high workload, frequent testing, strict obligatory attendance and increasing responsibility for patients (123, 124), which can result in negative consequences for learning. In addition, medical students can, after a few years in their medical education, be presumed to have excellent conditions for studies because of previously high grades and continued success in the programme's learning system. Medical students in Sweden usually have a high capacity for learning and can be assumed to have excellent conditions for self-regulated learning, which can affect the results of Study III. Finally, the goal of being able to interpret the ECG as a student and while becoming a physician can be a substantial factor driving motivation to learn ECG interpretation. For the students, less clinically relevant skills or knowledge can provide other considerations than the observed decision model.

It is difficult to know whether there are gender differences in the studies. In Study III, women had significantly better results at the ECG station in OSCE, while in Study IV women had significantly lower scores on a written test. However, in Study III, there was a larger proportion of women who used the web-based ECG resource. At the same time, we saw that female medical students had a better correlation between their evaluated knowledge of ECG interpretation and their performances at the ECG assessment. This suggests that there can be a gender difference in ability to assess the need for resources.

To be able to understand student processes in blended-learning settings, we must understand learning from several perspectives. Our proposed framework is built upon self-regulated learning and could be used as a framework for educators in ECG, but it must be further investigated with a broader perspective.

6.1.3 What learning effects are connected to a web-based learning resource?

In Study I, we evaluated a possible difference in ECG skills between a group of students who had access to an additional resource of web-based education used for self-studies. The intervention group improved learning with an effect size of 0.65 (Cohen's d^a) compared to the control group. The effect size can be referred to as medium to large (80).
The effectiveness of web-based education compared to another type of education or compared to no education has been debated (125). Generally, in experimental or randomised studies, the effect size can be explored with more control. The disadvantage is that it can be challenging to correlate the environment in those research situations to the reality of learning (126, 127) unless it is intended to replace one format with another. Randomised media comparative research is difficult to apply to the blended-learning situation, and the students seem to need more possibilities and broader learning resources, not less. Traditional ECG education appears to work well in students' experiences (Study IV) (72, 128**).** By adding a web-based ECG-learning resource to traditional face-to-face learning, an extra medium learning effect can be expected, which has been confirmed by several other studies (26, 70, 75).

6.1.4 Students experience of the overall ECG-learning resources

Clinical rotations
Study III indicated that clinical rotations were important for students. It is, therefore, surprising that the students in Study IV expressed that they were less positive about an opportunity for learning ECG interpretation during clinical rotations. Speculatively, this can be seen from different perspectives. It can be an expression of the fact that the time for students to gain clinical skills and knowledge is reduced and rotations are more focused on practical health care provision than education. A second explanation may be that less experienced medical colleagues teach. Or the meetings between students and clinical teachers serves a different role, such as reconciling competencies or creating learning goals based on a more clinical context than during the sixth semester of internal medicine, as the student achieves a deeper and broader clinical insight. Students during the sixth semester (the beginning of clinical semesters) have many new impressions and encounter new learning situations, including performing clinical rounds, keeping a journal, taking patient anamnesis and performing physical examinations. All skills are relatively new and associated with social interaction with the patient or other health professionals. It is also possible that the time since the student had this experience is too far in the past that they forgot the benefit.

Clinical experience from students working as assistant physicians
Another of our findings concerning student clinical experiences is the possible influence of supplementary clinical teaching experience in addition to their clinical studies during the semester. In Sweden, medical students have the opportunity to work as an assistant physician from the ninth semester. In Study IV, we recognised that students who had this working experience had significantly higher scores on the ECG test.
Maybe those students have prepared themselves with repetition of ECG skills before their work period, and that occasion to practice is the causal relationship. In a recent study by Boutis et al. concerning interpretation of X-ray images, significant differences were seen in students using repetition versus those who did not (129). At the same time, we know that occasional practice does not necessarily affect competence for more than a few weeks (26, 27). Possibly the students increased their ECG interpretation volume during work hours, and this made a difference. We know that skills are positively correlated to the number of ECGs that the student has been trained on, at least in the short term (130). Another effect that could

explain increased competence is that these students already have superior competencies, and this was why they were chosen to work/felt safe to work as an assistant physician. Regarding the clinical experience, we know that knowledge of ECG interpretation increases to some extent during particular residencies (ST-tjänst), such as cardiology (131).

However, we do not know how much clinical training generally adds because there are examples of residencies where physicians lose knowledge over time (12). What is evident is that physicians need to practice more ECG interpretation during residency (12, 131-133).

Based on our and others' research for the past ten years, the possible advantages of using web-based education for medical students are still largely unexplored.

6.1.5 Graduate students' skills in clinically relevant ECG interpretation

Thirty-nine percent of the graduating students in Study IV stated that they were unsure of basic ECG interpretation skills. The students' test results confirmed their lack of skills, with poor scores for ECG interpretation and for diagnosing life-threatening diseases. This lack of knowledge is worrying from the patient safety perspective, as the students will start working as either assistant physicians or as medical officers as part of their internships soon after their examination. However, this result is not specific to our study. Four other studies demonstrated results in line with our findings (6, 22, 110, 111). Variations may be attributed to different degrees of ECG difficulty but may also be due to the to various instruction design differences in the assessments (134, 135).

The gender difference
The gender difference in Study IV is opposite to Study III but in line with a recent study by Kopeć et al., which found that male students were better trained in the interpretation of primary ECG parameters (22). The findings of student estimation of their ECG interpretation skills and correlation with diagnostic test scores is interesting. From a self-regulated learning perspective, this finding requires further investigation. Others have found similar correlations. Kopeć et al. found a difference in ECG competence between students describing their competence as good versus bad, but a gender analysis was not performed (22). Escudero et al., in a study on paediatricians, also found that ECG skills had a similar relationship between accuracy and self-perceived confidence. No gender analysis was done in this study either (136). The aspect of possible gender difference in comparison of competence and student estimation of ECG interpretation skills is interesting and will need further investigation.

6.1.6 Limitations in the empirical studies

There are three limitations to Study I. A pre-test was not performed; therefore, we cannot know if there were any differences between the groups before the study. Not all of the students completed the voluntary diagnostic test, which is a source of potential bias. There is always a possibility of volunteer bias in these kinds of studies (137).

There are two limitations to Study II. First, the sample size can become an issue when differences among groups are small and research explores interactions rather than main effects (107). Second, a potential bias could be that the definition of a user was incorrect. To test for this, we performed a sensitivity analysis using three different user time cut-offs with the same result.

Two limitations were recognised in Study III regarding quantitative data collections. First, the OSCE test with only two ECGs has limitations, since it may be a ‘blunt’ way to assess ECG skills. A second limitation is that student activity in the ECG programme was measured through a learning management system. The system logged out when idle, and we do not know with certainty how active students were during training sessions in the programme.

In Study IV, we investigated students at a single university. Although the students were trained at four different hospitals, it is possible that results may differ for students from other universities. Second, the ECG test was not part of a mandatory examination. Thus, it is possible that the students did not perform to the best of their abilities in the test.

6.2 METHODOLOGICAL CONSIDERATIONS

This research project started with too narrow perspective on student learning. Learning from a broader perspective is complex. One way to do this research is to take the parts out of context and examine each piece separately. Instead, we attempted to have a more pragmatic, holistic perspective, and we have chosen to assume the prevailing situation when it comes to learning ECG interpretation. It has not been relevant to replace traditional education, i.e. lectures and seminars, which is relatively well-functioning in its pedagogy, but not sufficient. We have instead investigated the use and utility of a web-based ECG learning resource in a blended-learning context**.** In this case, this context involved voluntary use of a web-based ECG resource as a basis, which justifies the method. (i.e., to examine the user's intention and reasoning). The project was intended to increase understanding and explore opportunities from the learner's perspective. However, observational studies based on surveys and interviews mean lower levels of evidence.

6.3 FUTURE DIRECTIONS

A first step in analysing ECG education and student learning may begin in the structure of the medical programme. For the moment, most courses in the medical curriculum are time-based instead of competence-based (138). Students often have good enough skills and knowledge in ECG interpretation in connection with an education, and a high proportion of students pass the assessment in connection with teaching. However, when students complete the medical programme, they do not have sufficient knowledge from a patient safety perspective or what would be considered acceptable from a competency perspective (Study IV). However, this is not unique to Sweden. (6, 22, 110, 111). The students who have acquired sufficient knowledge and skills lose them quickly. ECG interpretation seems to be a skill that must be trained over a long time with regular repetition. For this, web-based ECG training could be useful in blended-learning contexts or as part of self-study. We currently do not know how this can be done most effectively.

One of the questions that should be asked is how can we support self-regulated learning in students? Is it through assessment or awareness of learning curves and how the student performs? In work by Hatala et al., interesting learning curves were seen both in terms of the proportion of correct ECGs and with regard to the time it took to interpret the ECG correctly, which shortened with the extent of learning (139). Another question that must be addressed is how much support should be given to the student. Should we, as teachers, set different goals that the students should meet when it comes to volume training along learning curves, as described by Hatala and others. Similar to these thoughts is the case in surgical education context, i.e., surgical simulation training. Mastery learning when, for example, a pre-set specialist skill level is defined, students practice against the goal and student activities/learning are matched against those skills, seems efficient (140, 141).

When it comes to designing web-based education, the social learning component has the potential of development. During the interviews in Study III, some students used the web-based learning resource together with other students, discussing the issues that came up during their learning. Kopeć et al. compared collaborative eLearning with self-learning. Results showed significantly better test results in the collaborative eLearning group (82).

If learning can be strengthened through longitudinal goal-directed ECG training, how should this be organised? To this date, no study has shown how to apply ECG interpretation knowledge in a way sustainable over time. Is there a certain amount of training that makes the knowledge and skills sustainable? In that case, how do we get there? Is it feasible within the medical programme? Or should it be part of the residency? What organisation will take that responsibility? Further, there is no knowledge of how much training in ECG interpretation is needed to create sustainable ECG skills that are available and useful in stressful clinical situations.

To summarise:
Studies are needed to investigate what repetition frequency is required for medical students to ensure longitudinal ECG skills.

Research should investigate how a web-based ECG-learning resource could be used more effectively during pre-clinical and clinical semesters in a blended-learning environment.

7 CONCLUSIONS

- Adding a web-based ECG learning resource in a blended-learning context seems to be more effective than just using traditional teaching methods.

- There are few barriers for the students to use a web-based ECG learning resource in a blended-learning setting and the students who use the resource seem to value it.

- A supplementary web-based ECG learning resource contributes to student learning based on principles of self-regulated learning in which students make their decisions based on a multitude of factors.

- Graduate medical students recognise the importance of ECG skills both in their present situation and in their future role as physicians. Despite this, more than one third of the students stated that they were unsure of ECG interpretation. The students' test results confirmed their lack of skills, with poor scores for ECG interpretation even in cases with life-threatening diseases.

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