Characterizing the Development of Expertise in Field-Based Research amongst Graduate Students in Ecology

Thesis submitted for the degree of
"Doctor of Philosophy"
By Mika Leon-Beck

Submitted to the Senate of the Hebrew University of Jerusalem
March 2013
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This work was carried out under the supervision of:

Dr. Jeff Dodick
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Abstract

Graduate research students are one of the major producers of scientific knowledge and technological innovation in society. Thus, improving their educational experience should take a prominent place in both research and policy. Surprisingly, there have been relatively few science education studies examining the world of graduate students, possibly because they were considered an elite and therefore do not experience most of the learning difficulties of younger students.

In fact, it is only in the last decade that this gap has been addressed. The few studies completed on graduate science learning have mostly focused on scientists in disciplines such as physics, chemistry and biomedical engineering. However, work in the history and philosophy of science has demonstrated strong methodological commonalities between two streams of sciences which are linked by their goal of research. These streams include the experimental, lab-based sciences (that rely on the experimental manipulation of natural phenomena) and the field-based sciences, such as geology, archeology and field-ecology which goal is reconstructing events and understanding patterns and processes from observed evidence gathered from the field. Accordingly, educational conclusions from laboratory-based studies cannot be validly superimposed on learning to implement field-based sciences as the field imposes a different set of conditions than those found in the laboratory.

Therefore, my study characterized the unique learning environment of field ecology research and how graduate students in this field develop research expertise. The scientific domain of ecology studies organisms in relations to their environment (which includes other living organisms and physical features). Ecological research areas of interest are diverse and accordingly, exploit different scientific methodologies which in fact represent the tension existing between the experimental and historical sciences mentioned previously. Field-ecology research (which my study focuses on) is pursed under the uncontrolled conditions of natural environments and thus exploits methodologies which represent the integrative (historical) tradition of ecology. This in contrast to the analytical (experimental) tradition of ecological research which is conducted under laboratory control conditions.

In order to describe the way in which the students developed their field-research expertise, I draw upon models of expertise as a theoretical framework for my analysis. These expertise models describe individual development. However, graduate
science students also belong to a research team which acts as a community of practice which shares the same values and research goals. For these reasons a further framework in my study, is based on situated learning, which includes the cognitive apprenticeship model.

My study has two goals. The first includes the characterization of the unique challenges and the learning components (knowledge, skills and motivations) that enabled graduate students to cope with said challenges in the specific domain of field-ecology research. Based on this characterization, my second goal is to compare the longitudinal changes in both the challenges and coping strategies (representing field-research skills) of the M.Sc. vs. Ph.D. students that belong to the same field-ecology research team.

To do this, I employed the qualitative in-vivo method, in which researchers study scientific teams who are conducting research in real-time. This study was conducted over a three-year period (2008-2011) by observing and filming the students as they work in the field; in addition I used qualitative methods of interviews, an open questionnaire (based on essential categories emerging from the interviews) and the collection of 'field assessment reports'. These reports were designed in order to permit the students to qualitatively evaluate their own research progress. The students answered them after each sampling season along their research which allowed me to track and measure quantitatively both the challenges that confronted the students and the coping strategies that they evolved while conducting field-research.

My sample consisted of a Professor/Advisor and her ecological research team (comprising two Ph.D. and three M.Sc. students, as well as two undergraduate research students) who are based in a centrally located, Israeli university. This group works on conservation biology issues such as the interaction between biodiversity, ecosystem functions and land-use change. The Professor of the research group, Yifat, is a relatively new lecturer (i.e. six years of experience) in ecology and conservation biology. As an additional perspective, I interviewed Yonathan a more experienced Professor (13 years) in field-ecology from a university in southern Israel.

Analysis of the qualitative data was based on the thematic analysis method and was done by triangulating the multiple data sources. This triangulation created a broader, more objective picture of how expert research practice was developed amongst my subjects and thus increased the validity of this research. In addition to
the qualitative analysis, the 'field assessment reports' were also transformed from qualitative data to frequencies which permitted a better comparison of the development of expertise between the M.Sc. and Ph.D. candidates. Inter-rater reliability of 94% was measured amongst five science education Ph.D. students who independently analyzed a representative subset of my data.

With regards to my first research goal of characterizing the learning environment of field-ecology research, my findings conclude that students' two major challenges in the field were the uncontrolled nature of research, and the setting of their research. The former includes challenges regarding (uncontrolled) environmental conditions, as well as applying field-research methods; the latter is concerned with the isolation of the students from authoritative guidance and also their interaction with research assistants.

Three learning components were found to enable students to cope with the complexity of their field-based research: Knowledge, Field-based research skills and Motivation. Knowledge elements represent the declarative and procedural knowledge needed for implementing field-ecology research. Field-based research skills are concerned with the (metacognitive) coping strategies which the students adopted to bridge the dynamic tension between their idealized research protocols and the reality of the field. These strategies were classified as being 'protocol-dominated' [PD] (i.e., implementing only what is possible as defined in the research protocol), 'intermediate' [INT] (i.e., using the planned protocol with immediate flexible changes in the field) or 'field-dominated' [FD] (i.e., planning for conducting the research based on the reality of field conditions). Additionally a strategy which was mentioned by the expert Professors was termed PD2 and included making an educated decision to maintain the protocol. Finally, the component of Motivation represents factors that encouraged or discouraged the students’ research and were specified by their intrinsic or extrinsic orientations.

Each of these learning components was essential on its own for transforming a novice student to a researcher in field-ecology; however understanding the interactions among the different components permitted a fuller understanding of the learning process. An example for this interaction was evidential when experiencing field complexity served as a strong source of motivation for students to acquire the knowledge needed to develop research skills. Field experience is so significant because ecological research demands that students (often) work independently

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isolated from authoritative experts. Subsequently, this teaches them to adopt strategies that best solve the current challenge they face.

Another motivational consequence of complexity is the fact that it imposes itself the minute inexperienced students venture into the field; their lack of experience in activating their procedural knowledge in authentic research environments can be potentially frustrating which initially can negatively impact on (some) students’ motivation, which then affects how they execute their research. However, as they accumulate field experience, while acquiring the (mainly procedural) knowledge and skills needed to overcome the field’s complexity, students’ motivation improves. Another factor which significantly affected my subjects’ practice was their intrinsic motivation, consisting of deep-set interests in their particular discipline which drove them to improve their knowledge and research skills.

The results of my second research goal (i.e., comparing the process of expertise acquisition between M.Sc. and Ph.D. students, respectively) showed that the M.Sc. students lean more heavily on both their advisor and their (advisor-designed) protocols in contrast to the Ph.D. students who were more independent and related to their advisor as consultant / partner rather than one who dictates the research direction. It seems that the involvement of the students in the preparation of the research plan, which makes them better aware of the field complexity, can also enhance their ability to cope with research challenges by adapting their protocols to the changing conditions of the field.

Concerning specific challenges, the M.Sc. candidates were most affected by practical issues of methods and tools (chiefly in their 1st research year) and environmental factors (particularly in the 2nd research year) which weighed on them heavily, given that that they needed to finish their research in a rather short time period; in contrast, Ph.D. students forge their own direction and hence were concerned from the beginning of their research with core features of ecology as a science, such as unexplained variance and the conditions of their research plots.

Moreover, working with research assistants in the field, which created challenges connected to training, deployment, and subjective sampling were reported only by the Ph.D. students, primary in their 2nd research year. This challenge was directly related to the increasing complexity of the Ph.D. students' research which in the 2nd year included multiple experiments and thus necessitated more assistants. Such a challenge is likely not exclusive to Ph.D. students in field-ecology research.
The differences between Ph.D. and M.Sc. students were also reflected in their coping strategies. The M.Sc. students clearly leaned on their protocol which was reflected by their strong use of PD strategies throughout their research. However, their Ph.D. counterparts developed the experience and confidence to make both subtle and radical changes in their protocols, when needed.

These results have practical implications for science education. Understanding the unique learning environment of field-ecology research can improve the training of graduate students in acquiring expert research competencies. Advisors should improve their students' recognition of the dynamic tension existing between the research protocol and the reality of field conditions so that they are prepared to adapt their reasoning and actions accordingly. Knowing that there is a set of strategies available for problem solving can promote the students' ability to make the most educated decision possible when coping with their field-based research challenges.

Moreover, in line with the cognitive apprenticeship model, my findings suggest that novices will implement their research protocols more effectively if their advisor, or even an experienced student, is present at the beginning of the research to scaffold the skills needed for coping with such complex, uncontrolled conditions. Furthermore, in order to increase student-advisor communication, a metacognitive discussion on the challenges and the coping strategies can be achieved by using a written 'field assessment report' and also in research groups and seminars.

Additionally, aside from its impact on graduate education, this study can also impact students at other levels of the education process. To a large degree the sciences that students encounter before university are weighted towards the experimental lab-based experience. I suggest that undergraduate ecology courses as well as K-12 inquiry-based ecology learning should be more strongly situated within natural field environments. This can provide the students with the perceptive of field-ecology complexity as well as the opportunity to develop more quickly the knowledge needed to cope with ecological research challenges.
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1. Introduction

1.1 Overview

In the last forty years, the education community has invested heavily in expert/novice research (Sternberg, 1999). Its original goal was to define the characteristics and actions of experts so that these features could be adapted to the various needs of both artificial intelligence as well as the training of novices (Bransford, Brown, & Cocking, 1999; Chi, Glaser, & Farr, 1988). However, as Alexander (2003a, p.10) noted, despite an impressive list of accomplishments, it has "proven difficult to translate the findings of the past generations of expert / novice research into educational practice".

One reason for this translation problem is that traditional expertise research programs were not specifically undertaken with schools or students in mind (Alexander, 2003b). Another translation problem can be traced to the multifaceted, and dynamic nature of formal schooling and the difficulty of traditional expertise approaches to relate to this unique, socio-cultural context (Sternberg, 2003). This understanding is supported by the situated learning movement which ties learning to an interaction between students and specific tools and activities in their authentic environments (Brown, Collins, & Duguid, 1989; Driscoll, 2005) or these reasons, models drawn directly from school experiences (at all levels of the educational system) rather than superimposed on them based on theoretical expert models are necessary to bridge the chasm between current understandings of expertise and educational practice.

One group of students that is in great need of expert learning models rooted in actual school experience is graduate students. Graduate students are one of the major producers of scientific knowledge and technological innovation in society. Thus, improving their educational experience should take a prominent place in both research and policy. Surprisingly, there have been relatively few science education studies examining the world of graduate students, possibly because they were considered an elite and therefore do not experience most of the learning difficulties of younger students. As I will show in my literature review, this paucity of research is especially the case for M.Sc. research students who have received almost no attention by science education researchers.
In fact, it is only in the last decade or so that this research gap has been addressed. The few studies completed on graduate science learning, as will be seen, have mostly focused on scientists in disciplines such as physics, chemistry and biomedical engineering. However, work in the history and philosophy of science has demonstrated strong methodological commonalities between two streams of sciences which are linked by their goal of research. These streams include the experimental, lab-based sciences (that rely on the experimental manipulation of natural phenomena) and the field-based sciences, such as geology, archeology and field-ecology which goal is reconstructing events and understanding patterns and processes from observed evidence gathered from the field (Dodick & Argamon, 2006). Accordingly, the results of such laboratory-based studies cannot be validly superimposed on learning to implement field-based sciences as the field imposes a different set of conditions than those found in the laboratory.

These arguments about the importance of domain for different educational contexts has strong support from Ericsson and Lehmann (1996) who in a review of many of the expertise studies conducted up to the mid 1990s, found that (1) measures of general basic capacities do not predict success in a domain; (2) the superior performance of experts is often very domain specific and transfer outside their narrow area of expertise is surprisingly limited and (3) systematic differences between experts and less proficient individuals nearly always reflect attributes acquired by the experts during their lengthy training. In sum, this justifies my focus on a specific domain.

Moreover, most of the previous studies on the graduate students learning do not focus on what Sternberg (1999, p. 359) calls developing expertise: “the ongoing process of the acquisition and consolidation of a set of skills needed for a high level of mastery in one or more domains of life performance”. Simply put, expertise develops over time, and so in order to understand it and even enhance it educationally it should be traced systematically over time. Thus, in my longitudinal study I discuss how a group of graduate ecology students learn the expert competencies needed to pursue field research. This in-depth qualitative study is presented in two parts. The first part characterizes both the unique challenges and learning components (knowledge, skills and motivations) that enabled graduate students to cope with said challenges in the specific domain of field ecology research. Based on this first study, I then compare the longitudinally changes in my M.Sc. and Ph.D. subjects in how they
perceive these challenges and how they develop coping strategies (represented by field-research skills) as they gain greater competence as field researchers.

My study has significance for science education for several reasons. First, for field-ecology graduate students, providing them with a better understanding of their unique learning environment and its constraints can assist them in understanding the affective and cognitive learning components needed to improve their research abilities. Additionally, by providing them with developmental indicators (based on how they respond to challenges) they can improve their ability to monitor their own learning so that they can progress over time.

Moreover, in line with this desire to provide indicators for monitoring learning progress, it must be remembered that graduate science students play an important role in science education, by teaching lab and field exercises to undergraduate students (Feldman, Divoll & Rogen-Klyve, 2009; 2013). Thus, graduate students who can better comprehend the unique learning environment of the field, as well as monitor their progress over time will also be able to better educate undergraduates, some of whom will become the future science teachers.

Secondly, studies like this can provide Professors with tools to better advise their graduate students. Indeed, a strong constraint on advising in field sciences is the fact that Professors cannot always participate in their students’ field work (Roth & Bowen, 2001a, 2001b). This means that they cannot directly scaffold their students’ research practices, which is an essential part of any “cognitive apprenticeship” in the sciences. (One might contrast this difficulty in field science with the relative ease of advising laboratory-based students who are usually located nearby to their advisor).

In fact, Feldman, Divoll and Rogen-Klyve (2009) have shown that in general many Professors give little consideration to how they educate new researchers and instead base their mentoring on their own experiences. This is unfortunate as Curtin, Stewart & Ostrove (2013) have shown that advisors play a key affective role in the experiences of (doctoral) students as they navigate their way through graduate school, helping them to develop a sense of belonging, so that they perceive themselves as competent and productive members of the academy.

By articulating the knowledge, skills and motivation of graduate students in field-ecology, my study provides Professors with better strategies for training such students. Understanding how a novice perceives these learning components can assist Professors to better prepare and guide their students to cope with the specific
challenges of this scientific domain. In addition, the second part of my study which compares how the M.Sc. and Ph.D. students respectively view challenges and cope with them, can also improve Professors ability to distinguish between these two cohorts in designing the necessary supports needed to enhance their students' research abilities.

Finally, aside from its impact on graduate education, this study can also impact students at other levels of the education process. To a large degree the sciences that students encounter before university are weighted towards the experimental lab-based experience. The development of a complete and integrated inquiry-based science curriculum will also require understanding about how field-based scientists do their research. This will enable educators to broaden the science curriculum to incorporate to a greater degree the field-based sciences (such as field ecology), and will expand students' understanding of different modes of scientific reasoning, as well as provide more opportunities for students to become interested in pursuing further education in science. This study is one of the steps toward better understanding how to improve the educational experiences of novice students in scientifically interpreting the natural environment.

1.2 Literature Review

This study is aimed at characterizing the learning of graduate student as they acquire the expert disciplinary practices for conducting field-ecological research. The justification for this study is based on the idea that the field-ecology is a unique domain and thus warrants investigation in order to improve the educational experience of its graduate students. Thus, I will begin my literature review with comparing the different domains in science to demonstrate what is unique about field-ecology. Then, I will present recent educational studies which examined how science is done in practice (on the graduate level). And lastly, I will review relevant models on the development expertise.

1.2.1. Comparing different scientific domains

This section briefly compares field and lab sciences to show how they differ methodologically and accordingly must be treated as separate domains. In recent
years, large numbers of scientists, philosophers, and educators have critiqued the idea of one universal scientific method (Cartwright, 1999; Cleland, 2002; Diamond & Case, 1986; Frodeman, 1995; Gould, 1986; Hacking, 1999; Rudolph & Stewart, 1998) to instead advance the proposal that different methodologies do play different roles in different domains.

This hypothesis is supported by philosophers of science who have defined two different streams of science which are characterized by different research methodologies. The first is experimental in nature and conducted within controlled laboratory environments; the second is historical in character and pursued in the natural environment of the field (Cleland, 2002; Frodeman, 1995; Mayr, 1985).

Dodick, Argamon and Chase (2009) differentiated these two streams of sciences by asking four questions which could be used to define these two streams: (1) Is evidence primarily gathered by manipulation or by observation? (2) Is research quality measured by effective prediction or explanation? (3) Is the goal of the research to find general laws or statements or ultimate (and contingent) causes? and (4) Are the objects of study uniform entities (which are interchangeable) or are they complex entities (which are each unique)?

Accordingly, experimental science gathers knowledge by controlled experimentation, in which natural phenomena are manipulated in order to test a theory. The quality of such a theory is measured by the consistency of its predictions with experiments, and ideally, such a theory expresses a general statement or causal law that is applicable to a wide variety of phenomena in many contexts. Finally, the form of this research is dictated largely by the study of uniform entities such as atoms; the fact that such entities are identical, or nearly so, makes the formulation of general laws possible in principle, and experimental reproducibility a reasonable requirement in practice.

On the contrary, the stream of historical sciences investigates causes that occurred in the past, and whose effects are often observed only after very complex causal chains of intervening events. Thus, evidence is often gathered by observation of naturally occurring traces of the phenomena, since manipulation is usually difficult to impossible (e.g., it is impossible to manipulate the macro-evolutionary change of a species in a short time period). This focus on past causation further implies that the ultimate test of quality in historical science is explanatory adequacy, because the
phenomena under investigation are unique and contingent, with a very low likelihood of repeating exactly.

The methodology of such explanatory reasoning derives from what Cleland (2002) calls the "asymmetry of causation", in that effects of a unique event in the past tend to diffuse over time, with effects being lost or muddled by other intervening factors. Making sense of this complexity requires, therefore, "synthetic thinking" in which one fits together complex combinations of evidence to form arguments for and against competing hypotheses (Baker, 1996).

In addition to sorting through such complexity, historical scientists must also deal with the complexity of the individuals under study. Unlike subatomic particles, or genes, which are uniform, entities studied by historical scientists (strata, human cultural remains, species) are unique, though often similar bodies whose precise configuration and function are not always recoverable. This eliminates the possibility of formulating universal laws, and allowing only statistical statements of relative likelihoods at best, so that arguments for and against hypotheses must be made on the preponderance of the best evidence. Thus reasoning about the relative likelihood of different assertions is common to the historical sciences' synthetic thinking.

These claims were empirically tested by Dodick, Argamon and Chase (2009) and Argamon, Dodick and Chase (2008) by comparing the discourse styles of peer-reviewed journal articles from fields in experimental (e.g. organic chemistry) and historical (e.g. paleontology) sciences. Using techniques from computational linguistics, a large number of peer-reviewed, journal articles from these two types of science were compared. This research team found that the style of writing in the historical sciences is readily distinguishable from that of the experimental sciences, and that the most significant linguistic features of these distinctive styles are directly related to the methodological differences posited by philosophers of science between historical and experimental sciences.

1.2.1.1 Ecological research
As this study focuses on the disciplinary practices of field-ecology research, it is important to address the specific characteristics of this domain in relation to the broad discipline of ecology to which it belongs.

Ecology is the scientific study of the organisms in relations to their environment which includes other living organisms (biotic components) as well as
physical features (abiotic components) such as the climate and soil type (Chapman & Reiss, 1995; Diamond & Case, 1986). Ecological research areas of interest are diverse and include topics such as ecological genetics, population dynamics, resource management, behavior, sociobiology and conservation. Consequently, in order to investigate these various research areas, the practice of ecological research exploits different scientific methodologies (Chapman & Reiss, 1995; Holling, 1998).

In fact, the diverse scientific methodologies in the discipline of ecology represent the tension existing between the *experimental* and *historical* streams of science (mentioned above). Accordingly, one ecological stream is *experimental*, reductionist and conducted in the controlled laboratory, whereas the other is integrative in character and takes place in the field. This idea was supported by Holling's (1998) declaration of "two cultures of ecology" which distinguish between the *analytical* reductionist attitudes as opposed to *integrative* systems approaches for analyzing populations and ecosystems.

More specifically the *analytical* stream of ecology, which is conducted under the control conditions of a laboratory, involves analysis of specific processes that affect specific variables (populations of individual species, levels of nutrients, flux of gases). It emerges from traditions of *experimental science* where a narrow enough focus is chosen in order to pose hypotheses, collect data, and design critical tests in order to reject invalid hypotheses. However, the second, *integrative* tradition of ecology is firmly based on field studies which focus on analyzing whole natural populations, ecosystems, and planetary dynamics. These type of studies include developing competing causative hypotheses and evaluating them by using information from the whole system (Holling, 1998).

Furthermore, field research is implemented in natural environments where organisms are neither distributed uniformly nor at random, forming instead some sort of spatial variance which creates diversity in communities of organisms, as well as in the variety of the observed biological and ecological events (Legendre & Fortin, 1989). This requires researchers to deal with field variation (also termed as ('environmental noise' (Green et al., 2005)) when planning, implementing and also when analyzing their field-based data.

Apart from Holling's (1998) bipolar perspective on ecological methodologies (which is similar to the *experimental* vs. *historical* description of all the sciences), Diamond and Case (1986) suggested a tripartite division of ecological experiments
which adds a further in-depth understanding of different types of ecological research, and in particular a differentiation of its two field-based practices. For that reason, I used Diamond and Case tripartite model in order to more accurately classify my subjects' research domain.

Their classification distinguished between Laboratory experiments (LEs), Field experiments (FEs), and Natural Experiments (NEs). LEs are coincident with Holling’s (1998) analytical pole in which ecologists manipulate a small number of variables under controlled laboratory conditions, which also allows for a nearly limitless number of replications. As a result, ecological LEs permit a high regulation of independent variables, but they can be unrealistic, as they do not account for the interaction between the large number of biotic and abiotic factors in natural environments. Additionally, because researchers need to maintain viable laboratory populations of organisms for many years, this limits a LEs’ scope.

In comparison, FEs and NEs are implemented under the natural conditions of the field; thus they are both included in Holling’s (1998) definition of integrative ecological research. FEs manipulate no more than a few variables in the natural conditions of the field. FEs expand in realism, in contrast to LEs by experimenting with actual wild communities, although it is much more difficult for FEs to control their variables, as opposed to LEs, due to the complex nature of the field.

Lastly, NEs are based on evaluating the effects of natural (i.e. not manipulated by the experimenter) perturbations in the field. When conducting NEs, the researcher must also choose a control, similar to the experimental site, but that is untouched by the same natural perturbations. This method gains on both LEs and FEs in terms of scope and realism, but concurrently NEs have no control over their independent variables due to the confounding complexity of field conditions, which remain wholly uncontrolled. In style and scope NEs are most similar to the historical sciences mentioned previously.

My study's subjects implement NEs which means that their research is at the mercy of complex field conditions. Such complexity was a chief source of challenges that these new researchers had to respond if they were to conduct successful research. And it is these challenges, and the students’ strategic responses, that I expose and longitudinally track in my study in order to build a more complete representation of the development of expertise in field-ecology research.
1.2.2. Learning to do scientific research

Research emanating from graduate science students is a source of pride and innovation for nations around the world. However, there have been relatively few expertise studies concerning graduate science research experiences; this is surprising as graduate students are the perfect candidates for expertise studies as they make the "critical transition" from being a course-taker, which is a familiar role, to that of an independent researcher and scholar, which is an unfamiliar role (Lovitts (2005), p.138). Indeed, most of the research conducted on students learning to do authentic research has examined precollege students (Barab & Hay, 2001; Bleicher, 1996; Etkina, Matilsky, & Lawrence, 2003), undergraduates (Hunter, Laursen, & Seymour, 2007; Kardash, 2000; Lopatto, 2004), and pre- and in-service teachers engaged in short-term research (Brown, Bolton, Chadwell, & Melear, 2002; Schwartz, Lederman, & Crawford, 2004; Varelas, House, & Wenzel, 2005).

This does not mean that the graduate experience in general has been totally ignored by the academic world. Graduate education has gained the attention of sociologists and anthropologists, as far back as Bucher and Stelling's (1977) ethnographic research about the last three years of training for medical students in psychiatry, internal medicine, and biochemistry. In their research they suggested that graduate students learned by trial and error as well as by help from others. More recently there have been an impressive number of studies dealing with the socialization and enculturation of doctoral students (Becher, Henkel, & Kogan, 1994; Burgess, 1994; Delamont, Atkinson, & Parry, 2000), as well as on the role of advisor supervision in the doctoral experience (Curtin et al., 2013; Heath, 2002), and finally practical guides for improving doctoral education (Delamont, Atkinson, & Parry, 1997). It should be remembered that these studies deal exclusively with doctoral students and not M.Sc. students, something which my study adds, as M.Sc. research has an important place (amongst other places) in Israel universities.

So too, the discipline of science education has also started looking at graduate education. Thus, Tai and his colleagues completed a major survey-based study on the education of physics and chemistry graduate students - Project Crossover. This project has examined a diverse set of issues including: possible conflicts between the choice of a science career and family life (Wyss & Tai, 2010), the experiences reported by graduate students that first engaged them in science (Maltese & Tai, 2010) and the
effect of goal orientation toward the pursuit of a graduate degree in physical science and how it influences later success outcomes of practicing physicists and chemists. Similarly, Stucky and Bond-Robinson (2004) and Bond-Robinson and Stucky (2005) focused on students and their interactions in organic chemistry laboratories.

Nersessian (2005) has specifically been examining the world of biomedical engineers; she demonstrates that problem solving in science laboratories involves a process in which graduate students and their Professors adapt their laboratory environment and methods to overcome new research conditions in "cognitive partnerships". Such cognitive partnerships develop slowly until the graduate students become expert at knowing what questions their equipment and techniques can answer. They act as means for the students to cope with the complexity of their specific lab-based research environment. In my study, I also expose a set of strategies that the students use to cope with their unique field-based research environment. In contrast to Nersessian’s sample which worked in an equipment-intensive, engineering lab, my sample had to cope with the uncontrolled environment of the field, which at the same time was less equipment intensive.

Esterman and Yarden (2005) studied the cooperation amongst an interdisciplinary team of systems biologists participating in group meetings. This work contrasted the challenges faced by the graduate students, who had either physics or biology backgrounds to integrate the knowledge base and scientific worldview of the other team members of the group.

The common feature of all of these science education studies is that their settings were the controlled environment of the laboratory (and the experiments conducted there). However, since my study is focused on field-based learning, given my earlier arguments about the importance of domain and transfer, I was careful in relying too heavily on research whose subjects were lab-based; fortunately, there are at least a few studies that have dealt with graduate student experiences in field sciences.

The first such studies were the sociologies of graduate experience by Delamont, Atkinson and Parry (2000) and Delamont and Atkinson (2001) (which included earth science, physical geography and human geography). Amongst other findings, the authors contrast the stage-managed lab and field experiences of the typical undergraduate student with the daily experience of graduate students who do
not achieve stable, useable research results until they have mastered the tacit craft skills of their discipline.

More recently Flash-Gvili and Dodick (2008) and Flash-Gvili and Dodick (2010) examined a team of integrative archeologists in Israel. Integrative Archeology is an historical-based science in which the practitioners reconstruct natural phenomena of the past by collecting and analyzing their uncontrolled traces collected in the field. In the specific research team that was studied in this research, the advisor places great emphasis on identifying a (significant) research question to investigate. However, at the beginning stages of their work, because of a lack of experience the students jump immediately into problem-solving mode before validating that fact that a specific phenomenon is worthy of investigation.

A third set of studies involving field sciences was conducted by Roth and Bowen (2001a, 2001b) and Bowen and Roth (2002, 2007) who examined the enculturation of field ecologists. Their work focused on the practical choices allowing novice ecologists to cope with the constraints of conducting independent fieldwork including its indeterminacy and open-endedness. Roth and Bowen (2001b) show that the aspiring ecologist realizes this task by generating multiple hypotheses that served as constraints to be satisfied. In addition, Bowen and Roth (2002, 2007) emphasize the importance of anecdotal narratives as a way in which ecologists develop insight into different ecological situations. Although, not found in the formal literature, such anecdotes also serve as a means of building social cohesion within the ecological community.

My study takes Roth & Bowen work on ecological fieldwork one stage further by exposing and longitudinally comparing the strategies that M.Sc. and Ph.D. students, respectively use to cope with their field-based challenges on their journey towards research expertise. Concurrently, these strategies are connected to specific learning components (knowledge, skills and motivation) identified in the cognitive and science education literature on expertise (which will be discussed in the next section).

Finally, Feldman, Divoll and Rogan-Klyve (2009; 2013) studied the interdisciplinary collaboration among a team of geologists, microbiologists and environmental engineers who were studying natural remediation at an abandoned mine. These studies differs from those done previously in that it qualitatively
distinguishes the different levels of (undergraduate to doctoral) students using their Professors' conceptualization, whereas previous studies focus on doctoral students.

In fact, Feldman and his colleagues used the theoretical perspective of situated cognition within communities of practice (Lave & Wenger, 1991; Wenger, 1998) to frame their studies. They found that in general, research groups are structured in two ways: "tightly-organized" and "loosely organized". Laboratory-based research groups are classified as "tightly-organized" since the laboratory serves as the center of action, where the students and postdoctoral fellows interact with each other and with the lead researcher on a daily basis and participate in group meetings. In contrast, in scientific domains that include fieldwork, research groups are classified as "loosely-organized". In these kinds of groups, the students work mostly individually and meet with their lead researcher to discuss their progress and provide guidance.

Moreover, Feldman and his colleagues showed that such students (no matter which group they belonged to) took on the role of apprentices (Lave & Wenger, 1991) and fulfill different roles as part of participating in a research team. They could be in the role of novice researcher, proficient technician, or knowledge producer with their role depending on their knowledge and skills, and their background degree programs.

Thus, Novice researchers are undergraduates and beginning graduate students who have little experience in scientific research and focus on collecting data. At the end of their Masters degree, when students develop the skills needed to analyze their collected data and report results to other researchers they become Proficient technicians. The final stage of Knowledge producers is expected from doctoral students who are able to formulate their own research questions, develop new research methods and add to the literature. Feldman and his colleagues concluded that as members of a community of practice research team members, including the professor and other students facilitate the development of the students along the continuum of roles.

My research builds on Feldman and his colleagues (2009; 2013) by adding a systematic development arc for both measuring and comparing the M.Sc. and Ph.D. subjects in my sample as they conducted their daily research in field ecology.
1.2.3. Models of developing expertise

Along with studies that examine specific domains (mentioned above), expertise research has developed models representing the successive development of students learning. I found such models to be very important in analyzing my longitudinal data, thus in the following I will review the relevant of these studies.

Dreyfus and Dreyfus’ (1986) model posits five progressive stages of development: Novice, Advanced Beginner, Competent, Proficient and Expert. As novices begin learning a skill, they first master the rules governing a situation and then how and when to apply them. As their level of skill improves, they tend to rely less and less on these rules, and can handle more complex situations with facility. At the higher levels of skills development, actions stem more from intuition than simply applying rules and accepted standards. At these levels, individuals perceive patterns in the situations they encounter and reflexively know what actions are appropriate.

In contrast to Dreyfus and Dreyfus’ (1986) strongly cognitive model which focused particularly on skill development as an indicator for transition in expertise, two additional models suggested by Sternberg (1999) and Alexander (1997; 2003a), respectively integrated additional affective components which influence the development of expertise. This approach has been supported by Pintrich (Pintrich, 2003) and his colleagues (Pintrich, Marx, & Boyle, 1993) who argued that traditional expert/novice research that considers expertise only from a ‘coldly cognitive’ perspective, overlooks powerful motivational and socio-cultural forces. Thus, Pintrich stressed that research is needed on the connections between motivation and cognition in academic settings.

Accordingly, Sternberg’s (1999) ‘developing expertise model’ combined four cognitive components (learning skills, thinking skills, knowledge skills, and metacognitive skills) with the component of motivation (Figure 1 in Sternberg, 1999, p. 362). Sternberg emphasize that these components are fully interactive and influence each other both directly and indirectly (for example, learning leads to knowledge, but knowledge facilitates more learning). Moreover, these components are domain specific; which means that developing expertise in one domain does not necessary lead to the development of expertise in another.

In my study, three of Sternberg’s (1999) components (Knowledge skills, Metacognitive skills, and Motivation) will be used to explain how my subjects cope
with fieldwork complexity. According to Sternberg definitions, **Knowledge skills** include two types of knowledge that are relevant in academic situations: **Declarative** and **Procedural** knowledge. **Declarative** knowledge is 'knowing that' and includes facts, concepts, principals and laws. In contrast, **Procedural** knowledge is 'knowing how' which is expressed in procedures and strategies including the tacit knowledge of how the system in which one is operating, functions.

Sternberg (1999) **Metacognitive skills** refer to people's understanding and control of their own cognition. Such skills are modifiable and encompass the knowledge of an individual in order to effectively solve related problems. One of these metacognitive skills is **strategy formulation** which in my study refers to the coping strategies the students used in order to cope with the challenges of their ecological field-research.

Lastly, **Motivation** is noted by Sternberg (1999) as the indispensable element for developing expertise; by this he meant that individuals need to improve their sense of self-efficacy in order to solve difficult tasks in their domain of expertise. This kind of self-efficacy, according to Sternberg, can result from **intrinsic** and **extrinsic** motivations. Accordingly, in my study I distinguish between my subjects' **intrinsic** and **extrinsic** motivation that both encourage and discourage them when conducting their field-research.

Unlike Sternberg (1999) model of developing expertise, which was applied to school-aged students, Alexander (2003a) and her colleagues (1997) modeled the learning experiences of (undergraduate) students in academic domains such as psychology, history, physics and biology. Similar to Sternberg (1999), Alexander’s ‘Model of Domain Learning’ (MDL) combined cognitive and affective learning dimensions which she labeled, respectively as **Knowledge**, **Strategy Use** and **Interest**.

**Knowledge** was represented in the MDL as **domain** or **topic** based knowledge. **Domain** knowledge deals with the breadth of knowledge within a domain (how much an individual knows about a certain domain). **Topic** knowledge is concerned with an in-depth understanding (how much an individual knows about specific domain topics). In fact, both of these knowledge types are similar to Sternberg's (1999) **declarative** knowledge, and are used in describing the knowledge components of my subjects' learning in the discipline of field-ecology research.
As the MDL was based on university students' text-based learning, **Strategy Use** was intended accordingly for *surface-level* vs. *deep-processing* strategies. The former strategy is used in order to make sense of the text, whereas the latter involve delving into the text and judging its creditability and mental representation. Since my study investigates the development of expertise in a very different domain of field-research, these text-based strategies were less suitable in my analysis of strategies use, which was in fact closer to Sternberg's (1999) problem-solving metacognitive skills (mentioned previously).

MDL's last dimension of **Interest** is divided into *individual* and *situational*. *Individual* interest is represented by the enduring investment of an individual in a particular domain, whereas *situational* interest is a fleeting arousal of attention stimulated by events in the learning environment. In my study, both of these interest dimensions were used to describe my subjects' motivation for implementing field-ecology research.

The specific dimensions of the MDL and their interactions are discussed by Alexander (2003a) along three stages of expertise: *Acclimation, competence* and *proficiency/expertise*. At *acclimation* students use surface level strategies as their knowledge is limited and fragmentary. When crossing into *competence* knowledge is more cohesive and students’ better understand the challenges so that they start using deep processing strategies. Finally, at the *proficiency/expertise* stage, knowledge level is high, and the subjects are even able to contribute knowledge of their own to the domain; additionally, they can investigate (recognize a problem and test it) and so rely heavily upon deep-level processing strategies.

Based on these three models of expertise development (Alexander, 1997, 2003a; Dreyfus & Dreyfus, 1986; Sternberg, 1999) my study also considers the acquisition of expertise as a process of development, rather than a binary categorization of novice versus expert. This idea was well defined by Sternberg (1999): "individuals are constantly in a process of developing expertise when they work within a given domain". Consequently, as all of these models recognize different levels of expertise development, in my study I tried to capture this process, by exposing and comparing the development of expert competencies over time amongst M.Sc. and Ph.D. candidates who travel a path towards greater expertise in ecological field-research.
Although I do draw upon these researchers’ models, it should be remembered that there are important differences between their conception and mine. First, my study differs from theirs by focusing on the challenging domain of conducting research in the specific field science of ecology; in contrast, Dreyfus and Dreyfus (1986) is a general expertise model, and Sternberg (1999) and Alexander (1997, 2003a) focus on learning in school-age and undergraduate students, respectively. Second, with regards to Alexander, her highest expertise level deals in part with investigating a problem. However, it is a given that in the case of graduate students they must be able to investigate a problem at the earliest stage of their research.

Furthermore, these models focus on individual reasoning; however, graduate science students often belong to a research team in which information is shared via seminars and informal discussions (Knorr-Cetina, 1999). Moreover, these “communities of practices” are imbedded in larger communities sharing the same values and research goals (Lave & Wenger, 1991; Wenger, 1998). This situated cognition is valuable in my research as the students participate in a “cognitive apprenticeship” (Brown, Collins & Duguid, 1989; Farmer, Buckmaster, & LeGrand, 1992). A cognitive apprenticeship “starts with deliberate instruction by someone who acts as a model; it then proceeds to model-guided trials by practitioners who progressively assume more responsibility for their learning” (Farmer, Buckmaster, & LeGrand, 1992, p. 42). As a cognitive apprenticeship proceeds students are provided with ongoing opportunities to express themselves and reflective thinking facilitated by an expert.

Beyond gains in understanding and exercising practical and cultural knowledge of a community of practice, Brown, Collins & Duguid (1989) discuss the benefits of cognitive apprenticeship in helping learners to deal competently with uncertainty—a trait particularly relevant to conducting scientific research. In their view, cognitive apprenticeship “teaches individuals how to think and act satisfactorily in practice. It transmits useful, reliable knowledge based on the consensual agreement of the practitioners, about how to deal with situations, particularly those that are ill-defined, complex and risky” (quoted in Farmer et al., 1992, p. 42). It teaches knowledge-in-action that is situated in authentic environments. So too, in my study I describe how my subjects belong to a research group (which include their Professor and other colleagues students) which acts as a community of practice which assists them to cope with the complex environment of implementing field-ecology research.
In summary, my review suggests that scientific disciplines which exploit different methodologies (such as *experimental* and *historical* sciences) must accordingly be treated as separate domains. As most of studies on the process of scientific learning were based on *experimental* lab-based disciplines, it is also important to understand the unique learning characteristics of *historical* field-based scientific disciplines such as *field ecology*. Thus, in this study, based on expertise development models, I longitudinally expose and compare how M.Sc. and Ph.D. students respectively learn the expert research competencies of their discipline.

2. Research Goals and Questions

The aim of my study is to characterize graduate student learning as they acquire the expert disciplinary practices for conducting field ecology research. In light of this aim I generated the following sets of goals and research questions:

1. **Characterizing the learning environment of field-ecology research**
   a. What are the principle **challenges** for graduate students learning to conduct ecological field research?
   b. What are the **learning components** (knowledge, field research skills and motivation) that enable graduate ecology students to cope with these research challenges?

2. **Comparing the process of expertise acquisition of M.Sc. vs. Ph.D. students in field-ecology research**
   a. How do the specific **challenges** of conducting research in field ecology change in importance in the view of the M.Sc. and Ph.D. students as they gain research expertise?
   b. How does the usage of different **coping strategies** to solve research challenges in field ecology change as the M.Sc. and Ph.D. students gain research expertise?
3. Methodology

3.1. Research design
This study addresses the question of how graduate students develop over time the competencies needed to conduct expert research in field-ecology. To do this, I employed the qualitative in-vivo method, in which researchers study scientific teams who are conducting research in real-time (Dunbar, 1993, 1995, 1997, 1999, 2000, 2002; Dunbar & Blanchette, 2001). This was done by observing and filming the students as they work in the field in addition to using supplementary qualitative methods of interviews, questionnaires and the collection of field documents.

The in-vivo method is a response to earlier attempts to understand how scientists reason. Originally, psychologists studied such scientific reasoning by testing individuals under laboratory conditions (Dunbar, 1995). Although producing important insights, this method had problems in generalizing about reasoning. First, it often used tasks that were not real scientific problems (e.g., Klayman and Ha (1987)). Second, subjects have often been non-scientists (e.g., Klahr and Dunbar, 1988), and even when scientists were studied they were typically assigned the same tasks as non-scientists (e.g., Mahoney and DeMonbruen (1977)). Third (and most important for my study) scientific research lasts from months to years and draws upon extensive domain knowledge, whereas lab-based psychology experiments last as little as ten minutes, and often involve no extensive domain knowledge (Dunbar, 1999).

Therefore, both ethnographers and cognitive scientists turned to methods permitting them to uncover scientific reasoning within real-world laboratories that reflected what scientists did when doing science. The ethnographers provided important detailed descriptions of the daily, social interactions amongst a variety of scientists including biologists (Knorr-Cetina, 1999; Latour & Woolgar, 1986), chemists (Law & Williams, 1982) and physicists (Collins, 1985; Knorr-Cetina, 1999).

In parallel, the cognitive scientist Dunbar pioneered the in-vivo approach which is similar to the ethnographic method in that it studies scientists’ interactions in real-time, but is more focused on reasoning, rather than social interaction. Dunbar's work specifically concentrates on how molecular biologists, during group-meetings, build collaborative models of the phenomena they study. My study differs from Dunbar’s in that its focus is on research practice that happens in real-time during
fieldwork, rather than during discussions in group-meetings. This approach is justified in that ecological expertise is developed primarily in the situated, authentic environment of the field (often when students work alone). Moreover, unlike Daunbar's work, my research focuses on learning, and not just reasoning so my sample specifically focuses on the relationship between graduate students and their advisor, rather than the mostly expert scientists of Dunbar's work.

Klahr & Simon (1999) critiqued complementary methods for studying discovery in science; although noting that the method of direct observation and analysis (i.e. the in-vivo method) is time consuming, they still gave it high marks for face validity, construct validity, short and fine grained temporal resolution, ability to find new phenomena, high rigor and precision, and being capable of explicating social and motivational factors.

### 3.2. Research sample

My sample consisted of a Professor/Advisor (Yifat) and her ecological research team (comprising two Ph.D. and three M.Sc. students, as well as two undergraduate research students) who are based in a centrally located, Israeli university. This group conducts research on conservation biology issues including biodiversity interaction, ecosystem functions and land-use change. Specifically, their research focuses on insect pollinators and pollination, as a central ecosystem service, and explores questions related to plant-pollinator interactions and pollination services to crops and wild plants. Another important research theme conducted by one of the M.Sc. students of this group (Uri) is the influence of post-fire salvage logging on soil-dwelling arthropods and their implications on biodiversity conservation.

This sample was selected after investigating the different ecological research teams in Israeli universities who were conducting field research. Three criteria were used for selecting this sample:

1. The Professor and her students were all interested in participating in my research, and all signed an ethical consent form that was vetted and approved by the ethics review board of my university. (All of the subjects' names have been altered to pseudonyms).
2. All students in the group implemented their research in the field (which was rare to find, as in most of the ecology groups we surveyed at least a few students, if not all, employ laboratory experiments).

3. The geographical area of the student's practice was accessible for direct observation over a three-year research period.

The Professor/advisor of the research group, Yifat, is a relatively new lecturer (i.e. six years of experience) in ecology and conservation biology. Before arriving at her present post, she pursued field ecology studies concerning biodiversity in agricultural and natural areas. She has also successfully published many articles in her field. As an additional perspective, I interviewed Yonathan a more experienced Professor/advisor (13 years) in field-ecology from a university in southern Israel.

Since my study is framed by the situated-learning movement (Brown, Collins & Duguid, 1989; Driscoll, 2005) and is concerned with the unique characteristics of learning to conduct field-ecology research, it is also important to describe my subjects’ learning environment. Figure 1 represents a general scheme for my subjects’ research design, which includes three major stages: Planning, Applying, and Analyzing. Other than acquiring background knowledge so that they could define research goals and questions, planning field-research demanded that the students conduct a preliminary exploration of the field in order to select appropriate research plots, as well as to practice their field-research methods. This was followed by designing a research protocol which included among other things the sampling timeline and the equipment needed for sampling. As planning is the first research stage, implementing each of these planning tasks was closely guided by Yifat, the advisor of the group.

When applying their research, the students took extensive measurements of the abiotic and biotic factors of their respective field sites. For that, they implemented various field-ecological methods, which included field-observations as well as an assortment of sampling techniques including: insect netting, pitfall traps and pan-traps (see Figure 2 for images and descriptions of these tools). At this stage each of the students tried to employ identical methods and tools during sequential sampling

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1 In fact, in the sampled group, the M.Sc. students received much more guidance in defining their research goals and questions in comparison to the Ph.D. students who were expected to lead their thesis research from the beginning of their research.
seasons in order to maintain reliability (represented by blue arrows on the right side of Figure 1).

However, since the students implement their research in the field, it is important to mention that these 'repetitions' are very challenging, as the environmental conditions are constantly and uncontrollably changing. This challenging situation, which is further detailed in the Results section of my study, occasionally caused the students to go back to the **planning** stage in order to adjust their research plan to the reality of the field-conditions (represented by red arrows on the left side of Figure 1). Moreover, unlike the previous stage of **planning**, which was closely guided by the advisor of the group, when **applying** their field research communication between students and advisor was less strong as the students implemented their field sampling mostly independently (consulting with their advisor by phone or in periodical meetings).

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**Figure 1**: General scheme for the graduate students practice in field-ecology research. This research design includes three major stages: Planning, Applying and Analyzing. Blue arrows (on the right) represent repeating field sampling that can occur after each of the Analyzing phases. Red arrows (on the left) represent adjusting the protocol design which can occur at each of the Applying or Analyzing phases.

Followed each sampling season, came the **analyzing** stage of the research. In order to organize a complete data set that includes both biotic and abiotic data from
the field, *taxonomic classification* of the biotic samples (e.g., insects, vegetation) was integrated with the abiotic data (e.g. temperature, humidity, radiation) that was measured during the field season. This *organizing* of the collected data into a complete multivariate data set enabled the students to apply a *statistical analysis*.

Each of the three stages took place in somewhat different environments. *Planning* was conducted in both lab and field. In contrast, *applying* was pursued only in the field, where the students worked (mostly) independently isolated from expert authority. Finally *analyzing* was done predominantly in the lab, where the students' advisor was close by so that she could assist them if needed.

![Figure 2](image)

*Figure 2:* Field-ecology methods and tools that the students implemented when applying their research: A- Observation on bees in an almond plantation; B- Netting bees with an insect-net in a desert habitat; C- pitfall trap for sampling soil-dwelling arthropods; and D- pan-trap: plastic colored bowl filled with soap water used for bees sampling (bees are drawn to the colored bowl, fall into the soapy water and die).

As this study compares the differences between *M.Sc.* and *Ph.D.* students, it is also important to be cognizant about their respective backgrounds, as well as the distinctive nature of the research programs. In terms of background, the three *M.Sc.* students in this group, Uri, Hadar and Tidhar, all have general undergraduate degrees in biology, with little to no research experience. Amongst the *Ph.D.* candidates, Ayala, has a concentration in ecology as she completed a M.Sc. study in biodiversity (which in fact took place in an environment that is similar to the one she is now exploring in her Ph.D.), whereas Gal, did his M.Sc. in molecular biology.

Regarding their programs, *M.Sc.* ecology students implement their research program over a relatively short time frame (2 - 3 years). In their 1st research year the students were actively applying their research protocol which was largely planned by
their advisor. In their 2nd research year, they were already under pressure to complete their studies. When working in the field, the students conducted their research mostly alone, isolated from their advisor.

In contrast, Ph.D. research is implemented over a longer period of time (4-5 years) and involves more independent thinking and research. In their 1st year, the students were very active in planning and implementing their research leading to a written research protocol. By their 2nd year their research becomes more complex as they added additional experiments to their research protocols, which in turn means that they had to adapt their existing methods to the new protocols. As their research requirements become heavier, the Ph.D. students relied much more on research assistants to help them conduct their fieldwork.

Finally, regarding the structure of the sampled research group, (Feldman, Divoll & Rogan-Klyve, 2009) it falls somewhere between being "tightly" and "loosely organized". In the former, the Professor of the group maintains a traditional laboratory in which the students work together and meet regularly to present their work. In a loosely organized group, the Professor builds relationships with individual students so that the lab (if it exists), is not a formal working environment. My research subjects sometimes collaborated in fieldwork, as well as gave group seminars; however, the field was their primary data collection point, where much of their work was pursued independently (guided by their advisor).

3.3. Data collection

Data was collected over a three-year period (from 2008 - 2011) and consisted of 442 in-depth semi-structured interviews recorded with the students and advisors, before; during and after each field season, as well as when it was necessary to clarify specific observations. Interviews were conducted in Hebrew and lasted between 60 and 90 minutes; they focused on issues such as students' opinions about the nature of their everyday research activities, field-research challenges and their way of coping with them, interactions with other students from their research group, expectations in terms

2 These 44 interviews with the research subjects included: 36 interviews with the students (nine interviews with Gal, nine with Ayala, nine with Uri, five with Hadar and four with Tidhar), four interviews with their advisor Yifat, and two interviews with Yonathan, an additional experienced advisor.
of guidance from their advisor, personal aspects motivating their research and their views on how one becomes an expert field-ecologist (see Appendix 1 and 2 for the protocols of the first interview with the students and advisors, respectively).

The interview questions were adapted from a previous research done by a fellow former student (who was also supervised by my advisor) who also examined research conducted by graduate students in a field based science - specifically, scientific archeology (Flash-Gvili & Dodick, 2008; 2010). The interview questions used in that research were validated by three experts in science education for both content and clarity. The content of these questions were then modified to the present research context, and further validated by three experts in science education, one of whom is Allen Feldman who also pursuing studies on graduate student research (Feldman, Divoll & Rogan-Klyve, 2009; 2013).

In addition, I collected 20 filmed observations of the students and their advisor while working in the field; a further set of 16 observations were collected during 12 group meetings and four departmental seminars. These filmed records added validity to my study by permitting me to directly witness (and review) how the students reacted to research challenges in the field.

Moreover, I collected field documents including maps, field journals and notes (see Appendix 2) and a "field assessment report" of my own design; this last item was completed by the students after each field session and permitted them to evaluate their research progress (see Appendix 3). 31 assessment reports were collected from the students along their research and allowed me to track and measure quantitatively both the challenges that confronted the students and the coping strategies that they evolved while conducting research.

The students' assessment reports were collected during the first two years of their study which represent a critical period of time when the students write their research proposals and implement them in the field. Additionally, M.Sc. students have largely completed their field studies after two years, and a strong focus of this study was the developmental comparison between the M.Sc. and Ph.D. cohort, so it was important for me to intensively track the first two years of study. Nonetheless, I continued to monitor the students in their third year via observations and interviews.

Finally, I also employed an open questionnaire (on year 2010), with questions based on essential categories emerging from the interviews, as well as the filmed protocols, which were connected to the development of research expertise (see
Appendix 4). In order to extend the reliability of the questionnaire results, it was also completed by Yonathan (an experienced advisor of another field-ecology research team, who I also interviewed for this research) as well as an additional research team from the same ecology department (consisting of an advisor, his 2 M.Sc. students and one post-doc). In sum 12 participants completed the questionnaire (two advisors, one post-doc, two Ph.D., five M.Sc. and two undergraduate students). Analyzing the questionnaire answers from these different cohorts conducting field ecology research added supplementary data on the learning process in this unique discipline.

3.4. Data analysis

Data analysis in this in vivo-based research is rooted in the methodological traditions of anthropology, psychology, and education. Analysis of the qualitative data was done during and after data collection, so it was possible to improve my protocols’ ability to uncover the fieldwork challenges and the students’ coping strategies.

The interviews were transcribed verbatim and analyzed using ‘Narralizer’ (Shkedi & Shkedi, 2004) a computer program permitting analysis of Hebrew-based qualitative data and based on Shkedi’s thematic analysis method (Shkedi, 2003; Shkedi & Shkedi, 2004). Based on Shkedi (2003), in the first reading of the interviews, primary categories were developed based on major themes emerging from the data. These categories served as codes for classifying each of the text segments. Codes were not preconceived, but empirical; each new code referenced a discrete idea not previously raised. As transcripts were coded, both the codes and their associated passages were entered into the ‘Narralizer’.

Correspondingly, other data sources collected in the research (i.e. field notes based on the filmed observations or "field assessment reports" and questionnaires) were coded in the same manner and added to the Narralizer analysis creating one comprehensive data set. Code words and their definitions were concurrently collected in a codebook. Groups of codes clustering around particular themes were assigned and grouped as family codes. Because an idea that is encapsulated by a code may relate to more than one theme, code words were often assigned multiple family codes. Thus, a branching and interconnected structure of family codes emerged from the text data, which, at any point in time, represented the state of the analysis. At that point, the branched categories were arrayed in a schematic map producing a focused emergent
framework of the data (See Figure 3 in the Results for one of these coding maps). This map was changed frequently, as more data was coded and added to the over-all analysis. Using this map I developed a broad model, which connected my findings with ideas found in the literature of science education and cognition.

Additional analysis of the "field assessment reports" was conducted by transforming the qualitative data to frequencies which permitted a better comparison of the development of expertise between the M.Sc. and Ph.D. candidates. Frequencies for the challenges of each student were obtained by dividing the number of a specific challenge reported by a student in all of the assessment sheets into the total number of reported challenges. Using these individual frequency counts it was possible to find the averages for the 1st and 2nd year of studies for the M.Sc. and Ph.D. cohorts, respectively. (The same operation was done for the major categories of "student consults" and "coping strategies" employed).

Data reduction was undertaken as the different sources of data were coded; it became apparent that a strong definition of "developed expertise" that emerged from this study was based specifically on the coping strategies that the students adopted for dealing with the complexity of research in the field. Thus, my qualitative coding coalesced around those factors that both challenged and permitted the students to cope with said challenges.

3.5. Validity, Reliability and Generalization

Validity of this qualitative study was maintained by triangulating between multiple data sources which created a broader, more objective picture of how expert research practice was developed amongst my subjects. Such triangulation also overcomes the specific problem of relying on interviews alone, as subjects sometimes describe their behavior as they would have liked it to be, rather than how it actually happened (Dunbar, 1999).

Validity was also insured by creating a 'thick' descriptive report that includes information about the context, quotations from the subjects and a visible conceptual discussion of the events that were observed (Shkedi, 2003). By supporting the theoretical claims with evidence collected from the subjects' account, the descriptive report gains in persuasiveness and plausibility (Riessman, 1993).
Finally as part of maintaining validity, I presented two seminars to the team members about my study. The first seminar was an introduction to science education and the qualitative method (so that they would have a better understanding about my research and their position as subjects of that research). The second seminar was held at the end of my data collection and included a discussion of selected results, which permitted further small adjustments to this analysis to effectively represent the data from the informants' perspective (Shkedi, 2003).

**Reliability** in qualitative research is obtained by consulting with research colleagues who get access to the original data and perform a separate and comparative (inter-rater) analysis (Riesman, 1993). In my research, this was done via comparative analyses performed by a forum of five science education Ph.D. students familiar with qualitative research methods. This forum examined a subset of the data, consisting of 40 quote segments at least a paragraph in length, where the subjects discuss their specific challenges and coping strategies. An average inter-rater reliability of 93.6% was measured amongst the five raters who independently coded these data segments.

Finally, **generalization** is reached in qualitative studies by focusing on the uniqueness of the case study. In contrast to the desire of quantitative studies to reach generalization by affectively sample the investigated population in the research, the aspirations of qualitative research are fundamentally different. Stake (2000) suggests that the main pursuit of (qualitative) case studies is to learn to know it well; not how it differs from others, but what are its characteristics and significance. In fact, by learning from the individual case – one can better understand the universal (Simons, 1996). In this study, analyzing the development of the same students over a three year period, revealed how their field research skills developed as they adapted their coping strategies to new research challenges. Understanding how field-research competence develops in this case sheds light on more universal aspects of ecological field-research and even on other sciences that also conduct field research.
4. Results and Discussion

This longitudinal study is aimed at characterizing the challenging learning environment of M.Sc. and Ph.D. students as they develop the expert disciplinary practices for conducting field ecology research. I will present my findings in two stages, according to my research goals and questions. Since this study represents a new area of research, the first step of my study is aimed at exposing the challenges and the learning components that enabled graduate students to cope with said challenges on their journey towards research expertise in field ecology. Subsequently, I will compare the longitudinally development of research expertise between M.Sc. and Ph.D. students in the domain of field-ecology.

4.1. Goal 1: Characterizing the learning environment of field-ecology research

'The problem is that in the field, the unexpected is expected; one cannot control all of the variables' (Goodenough, McGuire, & Wallance, 2001).

The implications of this seemingly simple quote are not obvious for novice field ecology researchers. How does one really expect the unexpected? And how can one learn to cope with the frustrating inability to control a research environment? The first step in answering these questions will be to expose the unexpected challenges of ecological field research, or more accurately its complexity. My analysis shows that this complexity is the central challenge which graduate field-ecology students must cope with during their research.

The second step involves detailing how the students coped with said complexity via a set of learning components that includes: knowledge, field-based research skills and motivation. This two-step process of understanding the unique learning environment of field-ecology research is represented in my research questions (1a, 1b) which I will answer in the following:

Research questions 1a: What are the principle challenges for graduate students learning to conduct ecological field research?
Figure 3 is the coding map delineating the sources of complexity challenging the graduate ecology students; it indicates two major sources of complexity. The first is caused by the uncontrolled nature of research; unlike their lab-based counterparts, field ecology students cannot conduct research in which they manipulate independent variables to test dependent variables under fully controlled conditions (Diamond & Case, 1986; Legendre & Fortin, 1989). The second is connected to the effect of research setting; by its nature, the field isolates students from direct supervision and large-scale collaboration common to students in lab-based research (Roth & Bowen, 2001b). This forces students to be independent researchers before they are ready to assume such roles. In the following discussion I will detail these two sources of complexity.

Concerning the first component of complexity, by their nature, field environments are uncontrolled and heterogeneous, such that no two locations in space and time are identical. This obligates researchers in field ecology to cope with uncontrolled environmental conditions which limit their research to periods when conditions are favorable; these conditions include biotic (e.g. existence of plants or insects) and abiotic (e.g. weather conditions) factors.

A crucial environmental condition mentioned by all of the subjects at the beginning of their research was the unavailability of suitable research plots containing the requisite plants and insects they attract. In many cases, the conditions existing in the field were not anticipated by their planned research protocol. These challenges were very common in the field-assessment reports, which the students filled out while working in the field, as can be seen in the following examples:

"Some ravines dried out, others turned off unexpectedly toward the agricultural areas." (Ayala, 1st year Ph.D.)

"I lack two plots of sunflowers with open margins. So I am compelled to work on two different sunflowers species that do not flower at the same time." (Gal, 1st year Ph.D.)

"I am uncertain that I can find appropriate plots that would be preserved in suitable conditions throughout the whole (sampling) season. The area is very dry." (Hadar, 2nd year M.Sc.)
Other than the unexpected conditions, as part of choosing appropriate research plots, the students needed to consider various environmental factors. An example of this challenge was noted by Ph.D. student Gal in his 1st year interview:

"In choosing research plots you need to take into considerations many things. [...] it's even more complicated because so many variables in the field interact with each other."

**Figure 3**: Coding map detailing the sources of complexity which challenged the graduate ecology students. Note that the use of different fonts (underlining, bold and italics) at different levels of the figure is matched with their use in the text.

Another complication in the search for plots is the weather conditions which affect flowering. In contrast to laboratory-scientists who can control and manipulate their experimental subjects, as well as the surrounding conditions, field researchers, such as my subjects, have to carefully study the weather in order to know how it might limit research success.

"It appears that [...] the season is going to be completely disrupted [...] I have real concerns about this season, about the rains and the mess [...] the whole thing is driving me crazy. Because of the early rains, there was early flowering, so the bees emerged early. And so I don't really know what this says about how the season will continue [...] because if there won't be good
rains now, there won't be flowering in the spring." [Ayala, 1st year Ph.D., interview].

For the students learning to effectively adjust their research to existing field conditions in their search for appropriate plots is time consuming, and sometimes it still ends with the disappointing decision of changing or abandoning the research plot, when conditions are unsuitable:

"I went searching for plots, [...] but it all looked so uncertain; the area is so dry now. [...] I said to myself, "I will be depending on the fact that the same plant I found would start flowering when there wasn't any rain yet", I don't know, I mean, there are just too many things I can't control [...]. Now it's all a matter of rain. I need to wait that it will rain. If it won't rain, there won't be any flowering, and I won't have a research subject for this year." [Hadar, 2nd year M.Sc., interview].

Other than affecting plots selection in the planning phase of the research, the weather conditions are also significant later when the students apply their research (and sample these plots), especially when the weather conditions change unexpectedly through time. This was emphasized in Yonathan's (an experienced advisor of another field-ecology research group) questionnaire answer:

"The problematic nature of our inability to predict the weather conditions causes many difficulties, so in many cases going out to the field is very different than the (initial) plan that was determined in the lab. This makes it more difficult to conduct the statistical analysis as well as collect data."

Aside from affecting their ability to properly sample their research plots, the uncontrolled and (often) harsh physical conditions (including the rough terrain and the need to carry all necessary equipment) affects the researchers, and the quality of their research.

"I have dislocated my knee [...] all of the heavy carrying. It is not a minor physical effort. [...] It happens. You move on." [Uri, 1st year M.Sc., interview].

Moreover, working intensively under harsh weather condition can also affect the students' motivation for conducting meticulous fieldwork, as was noted in several occasions by the students:

"It is 37° Celsius in the shade but it feels a lot more. Because it's also heavy air like this, there isn't even a small bit of wind. And the more you are present
in this heat, the harder it is for you.” [Ayala, 2nd year Ph.D., field observations].

“The biggest problem in the field was dealing with extreme heat conditions in the field. It can really affect your work.” [Tidhar, 1st year M.Sc. student, field assessment report]

Another factor which affected the students’ ability to conduct fieldwork is related to the unique research methods needed in order to implement field research. The challenge of applying (new) field methods and tools can be explained by the students’ practical need for their field experiments to ‘work’ (Delamont & Atkinson, 2001) and the ‘disappointment’ that occurs when they discover how hard it is to apply the methods and tools with which they had superficial familiarity from course work. For example, during his 1st Ph.D. year, Gal needed to construct a proper pan-trap\(^3\) that could be placed high enough to catch the bees feeding from the tall sunflowers (Figure 4):

“To place high pan-traps [...] it's a big thing. [...] where to get the equipment? [...] you also need to think how to stick it in the ground, which is not trivial at all. [...] it can't be too heavy. If you want to use pegs then you need to find pegs. It's an issue.” [Gal, 1st year Ph.D., interview].

**Figure 4:** Ph.D. student Gal sampling bees in the sunflower crop. On the left: Gal’s handmade high pan-trap; on the right: Gal observing the bees.

Another challenge in implementing field research methods was connected to time management. Due to the uncontrolled seasonal conditions, weather and even personal schedules, the students have limited access to their research environment,

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\(^3\) Pan-traps are plastic colored bowls filled with soap, usually placed on the ground to sample bees visiting nearby plants.
unlike lab-oriented students; this means that they must manage their time effectively to maximize their sampling efforts. This challenge was noted by Ph.D. student Ayala:

"The difficulty in the field is the uncontrolled weather which is just incomprehensible. [...] The fact is that you can only work during a certain time period and the need to manage all the sampling by the end of the season, that’s the main issue." [Ayala, 3rd year Ph.D., interview].

A final challenging factor related to research methods is the unexpected variance of conducting research in a natural environment. This variance is also termed by experienced ecologists as 'environmental noise' (Green et al., 2005) and refers to the fact that organisms in the natural environment are neither distributed uniformly nor at random, forming instead some sort of spatial variance which creates diversity in communities of organisms, as well as in the variety of the observed biological and ecological events (Diamond & Case, 1986; Legendre & Fortin, 1989). Yifat, the advisor of this group contrasted this challenge with the situation in lab-based sciences:

"I think that the level of uncertainty that one needs to relate to is higher in ecology [in comparison to lab research] [...]. Also with ecological questions, there is complexity especially connected to communities and things like these, where there are many species, many parameters." [Yifat, Advisor, 2nd year interview].

Below are two examples (from the questionnaires) presenting how this fundamental challenge was expressed in the research of each of the Ph.D. students in the group:

"Can we really investigate bees and how they change in time and space as a result of agriculture during the period of a doctorate when it is known that this is a group (of bees) which is commonly scattered in patches and changes from year to year for reasons we are not aware of?" [Ayala, 2nd year Ph.D.].

"A research of the type I am doing is correlative in nature and not experimental, so most of the results presented in it are explained in a correlative manner and not really "proven". It could always be argued that other variables existing in the system are largely responsible for the results I got, and not necessarily the variables I am ascribing to the effect." [Gal, 2nd year Ph.D.].
These students’ description of the challenging character of field research are supported by Holling (1998, p.4) depiction of integrative ecology research which is conducted in the field:

'*The premise [...] is that knowledge of the system ecologists deal with is always incomplete. Surprise is inevitable. There will rarely be unanimity of agreement among peers - only an increasingly credible line of tested argument.*'

Dealing with the challenges of an uncontrolled, harsh environment is made even more complicated because of its outdoor research setting, which isolated the students from other researchers. In some cases, the students’ research was done mostly alone which confronted them with three sets of challenges. Mental pressures are concerned with the lack of motivation that occurs due to research complexity, as well as the students’ concern for their safety while working alone in remote areas.

"The thing in working alone is that I get scared sometimes. This area is totally isolated so that if a snake bites me I don’t know what I would do [...] Also, there is no [cellular] reception there [...] so even though I try to let people know I am going to the field, if something would happen; then until late afternoon or evening when I won’t come back no one would even know. It’s not that I am usually so cowardly, but it worries me that it’s so quiet there; it’s insane how quite it is". [Hadar, 2nd year M.Sc., interview].

The technical challenges of working alone in the field occurred when students struggled to handle all of the sampling by themselves in the limited time-schedule of their research.

"I managed on my own. I can do it (the sampling) alone but it means constant running, without the time to stop and observe things. [When I am alone] all I can do is pick up the traps, and do what I must do. There is hardly any time for taking pictures, barely time to take datum points. I am very pressed for time." [Uri, 1st year M.Sc., interview].

"I have no doubt that I needed to work with more people. In order to succeed doing it [the sampling] in a defined time schedule I need more help." [Ayala, 1st year Ph.D., interview].

Finally, Professional challenges are related to working away from authoritative guidance (unlike lab-based students who have greater access to their
advisors); this forces the ecology students to make independent decisions even when they have only started their research:

"I felt a lack of someone else to consult with; this is important [...]. Where to place the traps? I have never done this, you know. Let’s say in the first site it took me an hour until I passed over the plot; I scratched my head. I didn’t know where to begin." [Uri, 1st year M.Sc., interview]

This is not to say that the students are unsupervised. As part of a ‘research group’, they are trained via a cognitive apprenticeship led by their advisor who provides strong guidance (especially) when the students complete their first assessment of their research site. Also, during their fieldwork sessions their advisor was available for problem solving over the phone, but as she (the advisor) admitted, such help, when working in the field is not as accessible as working next door to the advisor or even colleagues:

"In a laboratory a student doesn’t need to telephone me and if I don’t answer, then he needs to try again afterwards; he simply comes through my door to ask what I think. It seems to me that this [problem of] accessibility dictates many things." [Yifat, advisor, 3rd year interview].

However, in other cases, the students work with research assistants (undergraduate or graduate students) who help in sampling. All of the Ph.D. subjects, as well as (infrequently) one M.Sc. subjects (Uri) used assistants. These students reported that they were challenged by choosing appropriate assistants who then needed to be trained and effectively deployed in the field. All of these challenges were very new to the students, who in fact needed to act as "secondary-advisors" in order to have a constructive (rather than destructive) effect on their research. As this position was very new to them, it seems that the students relied mostly on their intuition in their decision making.

These decisions were reflected in the students' different requirements for employing assistants. Ayala, for example, emphasized the person's desire and ability to learn in the challenging environment of the field:

"A good assistant needs to have the ability to learn. [...] It's important to me that on the one hand there will be lots of excitement, but on the other hand the recognition that it (fieldwork) is not easy and things don't always work out, and that it's fine." [Ayala, 2nd year Ph.D., interview].
In Contrast, Gal's key demand was that his assistants had preliminary research knowledge:

"They (the assistants) need to know how to conduct research; for example, how to plan an experiment, to have a proper control treatment, to influence (the results) as least as you can. [...] This is why I want to choose people that have some kind of academic background in science." [Gal, 2nd year Ph.D., interview].

After choosing the assistants, the Ph.D. students had to effectively train and deploy them in the field. These responsibilities were also based on their intuitive recognition of what they thought they needed most as novice researchers in the field, as was noted by Ph.D. student Ayala in a 2nd year interview:

"With my comments, I tried to provide them (the assistants) with what I found missing (in my initial training), and it took me a long time to understand. [...] In the beginning I took them to try out the netting (one of this group's important field-research tools is using a net to catch bees, as seen in Figures 2 and 6), I demonstrated and they (the assistants) repeated after me, then I corrected their angle and told them to continue their hand movement without stopping. [...] Later on, I gave them the opportunity to do it alone, when I am there beside them, reminding them how it is supposed to look like [...] with lot's of encouragement [...] let's try again, you are very close [...] but also without over harassing them [...] and also knowing when to loosen my guidance and let them do it alone while I am looking from a distant without their notice. During that phase, they need to experience it on their own so they will have confidence."

In fact in her training decisions, Ayala was implementing the cognitive apprenticeship model (Collins, Brown, & Newman, 1989; Farmer, Buckmaster, & LeGrand, 1992) in which novices learn best by thoughtfully replicating the actions of an expert who models the needed competencies of a specific task.

Another challenging aspect of working with assistants was caused by the fact that sampling practices may be subjectively different from the student’s sampling which then adds to the aforementioned challenge of unexplained variance.

"Trapping [the bees] in the watermelon wasn't so hard. But when you are walking in the field, and while walking you need to observe as well as record, then one [of the research assistants] sees more [bees], and another [sees] less;
one would relate this [criterion] as a bee visiting [a flower] and the other [research assistant] would not. [...] So, this causes variance between samplers.” [Gal, 3rd year Ph.D., interview].

In fact, this challenging difference in between samplers in the field was also mentioned by Roth & Bowen (2001b, p.470) ethnography on field-ecology students who 'classified field objects differently'.

After exposing the complex nature of field-ecology research, I now move to the second and complementary step of understanding the unique learning environment of field-ecology research that enabled my subjects to cope with this complex research domain.

**Research questions 1b:** What are the **learning components** (knowledge, field research skills and motivation) that enable graduate ecology students to cope with their research challenges?

In representing how my subjects cope with challenges, I draw upon the expertise research of both Sternberg (1999) and Alexander (2003a) and her colleagues (1997). I do so because they integrate both cognitive and affective planes of learning and thus provide fuller expertise models than purely cognitive models. Nonetheless, I already noted that Sternberg (1999) applies his developing expertise model to younger students, whereas Alexander (2003a) and her colleagues (1997) MDL, although a model of learning in academic subjects, it does not consider the development of research competencies as my study.

My representation of field-ecology learning draws upon three components: **Knowledge**, **Field-based research skills** and **Motivation**. **Knowledge elements** represent the *declarative* and *procedural* knowledge needed for research within the domain of field ecology. **Field-based research skills** are the set of competencies that a student needs to develop in order to pursue research in field-ecology. **Motivation** represents the factors that encouraged or discouraged the students’ research. I will detail each of these components as well as their interactions in the following sections:

**Knowledge**

I begin with knowledge components, as these are often the first step in acquiring disciplinary expertise (Alexander, 2003a; Delamont & Atkinson, 2001; Dunbar, 1993;
Feldman, Divoll & Rogan-Klyve, 2009; Knorr-Cetina, 1999). In order to cope with the challenges of ecological fieldwork, students must acquire what Sternberg (1999), Dreyfus and Dreyfus (1986) and others call declarative and procedural knowledge.

Declarative knowledge is of facts, concepts, principles and laws; it is ‘knowing that’ (Sternberg, 1999; Sternberg, Wagner, Williams, & Horvath, 1995). As Alexander (2003a) shows declarative knowledge is further divided into domain and topic knowledge. The former deals with general knowledge about the breadth of a domain; in my case this refers to the breadth of concepts connected to ecology and conservation biology. The latter is concerned with in-depth understanding; thus, my subjects needed in-depth understanding of the biotic (e.g., organisms and plants) and abiotic elements (e.g., climate, soil type) within their specified research environment. Such declarative knowledge was largely acquired by my subjects prior to, or during the research, from external, formal sources such as courses or research literature.

The significance of the declarative knowledge in the student's learning was well represented in their answers to the questionnaire query: "How would you define an expert in field-ecology research?" 9/12 subjects referred to declarative knowledge (which includes general knowledge on ecology, as well as in-depth knowledge on the natural research environment) as a necessity for a field ecology expert. For example, Hadar, a 3rd year M.Sc. replied to this question as follows:

"A field-ecology expert must have extensive knowledge of ecology - population biology, key elements of natural systems, understanding the processes and relationships between populations and also between the living organisms and their abiotic environment."

In comparison to declarative knowledge, in the same questionnaire query, 11/12 students referred to procedural knowledge as essential for a field-ecology expert. For example, Ph.D. student Gal answered:

"A field ecology expert knows how to plan experiments, by considering all of the relevant variables, choosing research questions, which are on the one hand scientifically significant and on the other hand practically researchable. An expert knows how to plan an experimental system or a sampling that permits statistical reliability. An expert knows how to propose various hypotheses on systems which are yet unexplored."

4 For more details concerning the questionnaire participants see 'Data collection' in the Methods.
As Alexander (2003a) and her colleagues (1997) do not consider learning to implement research, they do not consider 'procedural knowledge' which (as was emphasized in Gal's quote) includes 'knowing how' to implement research methods, as well as knowledge about how the system in which one is operating functions (Sternberg, Wagner, Williams, & Horvath, 1995; Sternberg, 1999). In the case of field-ecology research, procedural knowledge consists of (technical) tools critical for planning, conducting and analyzing field research. As opposed to the controlled lab-based research, procedural knowledge, which is also needed for solving problems, research in field ecology must take into account unexpected and complex field conditions.

"In laboratory research everything is mostly under your control, I am sure there are all sorts of problems but you can't compare it to working in the field. [...] In the field you need to deal with the fact that almost everything is unexpected. [...] You need to improvise a lot more when you are in the field because you are mostly alone, not like in the lab, where you can always find someone to consult with when something problematic happens." [Tidhar, 2nd year M.Sc., interview].

Moreover, in contrast to declarative knowledge, procedural knowledge is learned mostly from informal and social-based sources, including interactions with advisors, and other group members. Most importantly, it is learned via personal interaction with the field. In fact, the significance of direct field experience as a major knowledge source for conducting field research was pronounced in the students' answers to the questionnaire query: "What helped you to progress in your research?" All subjects mentioned field experience when answering this question. The following examples below exemplify the importance of such experience:

"Just by working in the field, getting a sense of the field, helped me think about the research design, the analysis and other problems that can be significant". [Uri, 2nd year M.Sc. student].

"Repeated sampling of more and more field sites made me notice progressively how my assistants and I are working in the field, and how it might affect my research results" [Gal, 2nd year Ph.D. student].
"By experiencing variable field conditions and circumstances, I learn how to be more familiar with my research field environment. This also improved my ability to use various research methods." [Ayala, 2\textsuperscript{nd} year Ph.D. student].

Possibly, field experience is so significant in ecological research because the discipline requires students to work independently, isolated from authoritative, professional figures (Roth & Bowen, 2001b). Although my subjects received close guidance from their advisor, the procedural knowledge required for conducting their field-research was primarily learned and activated when engaging in authentic field problems, primarily while working alone. This argument, which represents the situated learning paradigm (Brown, Collins & Duguid, 1989) was well presented by Hadar in her 2\textsuperscript{nd} year M.Sc. interview:

"Especially in fieldwork, where you work mostly alone, you need to be very independent and to make quick decisions in the field as you work. So, you make mistakes from time to time, but this is exactly how you learn. When you see your mistakes, you know what you need to improve in."

Interviews with the students show that for most of them, understanding the importance of the situated procedural knowledge was acknowledged even before beginning their graduate research when they participated in field-based projects and practical courses. When were asked about their previous experience, the subjects recalled very few ecological courses that involved field-research procedural components. (This varied from none (Tidhar), 1 course (Hadar, Gal), or 2 courses (Ayala, Uri)). The students reported that these courses were not mandatory but they were significant in giving them "a taste of field-ecological research" (Gal, 3\textsuperscript{rd} year Ph.D.). The focus of these courses, as was noted by the students, was mostly on practical field methods and tools, but most importantly, these courses which included practicing independent fieldwork, demonstrated research characteristics which were needed for conducting a (full) field-ecology study:

"This (practical) course is one of the single courses I took (in my undergraduate studies) that I can really say contributed to my continuing on to learn a M.Sc., and in particular for conducting research. I was still inexperienced, but thanks to this course I had an idea of how field research is conducted; it made me understand the research process as a whole." [Hadar, 3\textsuperscript{rd} year M.Sc.].
These responses have important implications for how field ecology is taught at all levels of the education process, which I will discuss in the Implications of my study.

**Field-based research skills**

As noted previously, field-based research skills are the set of competencies a student needs to develop in order to pursue field-ecology research. In my view, such research skills both act upon and monitor what students do with their declarative and procedural knowledge while implementing their research. Thus, they are comparable to the strategic processing of Alexander (2003a) or the metacognitive skills of Sternberg (1999).

To understand this metacognitive process, I defined a set of indicators which emerged from my qualitative analysis, and defined how the students developed field-based research skills. These indicators are in fact a series of three metacognitive strategies which the students adopted to cope with the complexity of their field-based research; these strategies were represented in their context to the dynamic tension existing between the idealized research protocols as conceived by the student and the complex nature of field conditions they experienced in real-time (Figure 5). These strategies are termed:

A. **Protocol-dominated** (henceforth PD): Implementing only what is possible as defined in the research protocol (which can cause the student to reduce the plots or sites sampled).

B. **Intermediate** (INT): Using the planned protocol but making immediate flexible changes in the field in order to work under the present field conditions.

C. **Field-dominated** (FD): Alternative planning for implementing the research based on the reality of field conditions (and thus the initial protocol cannot be used in the field).
In his research, Dunbar (Dunbar, 1995, 1999, 2000, 2002; Dunbar & Fugelsang, 2005) also classified strategies that scientists used for coping with research challenges, although he focused on how molecular biologists coped with unexpected results in their lab-based science. He termed these three strategies as 'experimental replications', 'changing the protocol' and 'using a new protocol'.

I will compare my subjects’ coping strategies with those witnessed by Dunbar. Note though, that Dunbar’s classification is based on a scientists response to a result; in contrast, my classification differs as my subjects implemented their coping strategies from the planning of a natural field experiment through the analysis of results. I suggest that this difference is due to the field's uncontrolled complexity which imposes itself immediately upon the students' research protocols, which in turn demands a strategic response from them.

A PD strategy in my study, as defined above indicates that the students do their utmost to maintain their research plan. This strategy is a response to the lack of control that the (novice) students felt they had over certain variables in their research environment. As Ayala, a 1st year Ph.D. student succinctly acknowledged: "You work with what you have."

This strategy is comparable to Dunbar’s 'experimental replications' in which a scientist does not change his protocol in response to an unexpected result but simply runs replications to validate that result. Thus, like the PD strategy there is an effort to
preserve the research plan. However, it should be remembered that amongst field ecologists who rely upon natural experiments it is usually difficult to run replications, as they demand myriad time and resources unavailable to field researchers (Roth & Bowen, 2001b). Lack of replications is also linked to the fact that similar to historical sciences (such as geology) replicating the exact conditions leading to a result in natural, uncontrolled conditions is impossible (Dodick, Argamon & Case, 2009).

In contrast with the PD strategy some of the students expressed a FD strategy, which involves making fundamental changes in the protocol based on the reality of field conditions, and requires further thinking and consultation. It is comparable to Dunbar’s ‘using a new protocol’ in which the research plan is completely redesigned based on an unexpected result. In both our and Dunbar’s cases these strategies imply that the old plan cannot be preserved.

Between these two strategies exists an INT strategy in which the student independently tries to find an immediately flexible solution to the present field conditions, based on the current materials and methods available, which is then usually pursued independently by the student. This strategy is comparable to Dunbar’s strategy of “changing the protocol” in that in both cases the protocol is not abandoned.

The following discussion delineates how my subjects responded to the previously discussed challenges (demonstrated in Figure 3) via the three coping strategies found at major stages of their field-research scheme (illustrated in figure 1): prior to (Planning), during (Applying) and following (Analyzing) their field season. I will begin with the set of challenges concerning the uncontrolled nature of (field-ecology) research: Prior to a field season, students choose appropriate research plots, based on aerial-photographic maps. However, they often noticed that the maps were unmodified with regards to the actual environmental conditions (e.g. lack of flowers, or recent agricultural activities preventing access). The most novice researchers usually adopted a PD strategy in which they gave up on inappropriate sites which reduced the number of samples that they could take during their natural field experiments:

"The problem was really to find the research plots. […] Let's just say that we compromised on all kinds of things. […] A lot of things are not exactly the same [as seen in the aerial maps]; for example, some of the agricultural areas were not updated so I added them. I mean only when I was actually in the field, I saw that it wasn't like this. So, all of a sudden one of the plots was
reduced, because what we planned for wasn't in the field. There is nothing I can do." [Tidhar, 1st year M.Sc., interview].

Another example of adopting a PD strategy which emphasizes the difficulty of the students' necessity for implementing their research without the close guidance of their advisor was reflected in Hadar's field assessment report from her 2nd M.Sc. research year where she addressed her difficulty in finding appropriate research plots:

"I can't find enough appropriate plots. [...] I have reached a dead end. When working in the field I have no one to assist me, or more accurately there is no possible way for them to assist me. These are the existing conditions."

Students with some field experience adopted an INT strategy when they searched for alternative plots matching their initial research plan. Such alternative sites also permit students to maintain the number of samplings they planned to do in the original protocol, based on their greater sense of field conditions:

"If I come [to the field] and I found that, for example there wasn’t flowering exactly where I planned it to be, but instead it was 50 meters away […] then there is no problem as long as it’s the same distance [from the agriculture]. […] there isn’t one way of sampling in the desert. Every year it's [the flowering] in another place. […] You learn to live with this [change] because it doesn’t make a difference in the results. This is the exact same environment, the exact same plants, just this time it grew in this depression and not that one." [Ayala, 2nd year Ph.D., field observations]

Students implemented a FD strategy when the initial protocol ceased to provide a method by which it would be possible to choose appropriate sites and thus changed their criteria for choosing according to the reality of the field. For example, as a 2nd year M.Sc. student, Hadar discovered that she was unable to sample because of a lack of flowers. After discussing this issue with her advisor, she changed her natural experiment by adding honeybee hives, so that she would examine the influence of honeybees on wild bee habitats.

During the field season, the challenge in selecting plots and sampling them became even more complicated by the vagaries of weather conditions; for example, a critical problem was a lack of rain causing a lack of flowering. Such weather changes, in turn also affected the research methods, or more precisely, how the students apply field methods and tools. Students applying a PD solution to this problem simply ‘reduced the number of samples’ they took in the field.
Changeable weather conditions can also cause different plants to flower, which attract different bee types. In such cases, the students can apply an INT strategy in which they study these new bee species in the field so that they can adapt their sampling methods and tools:

"This was very challenging because due to the rain, there were lots of plants, so I needed to learn about many new [bee] species. You know, last year I had one "wave" [using the insect-net] here and there and that was all. Now I need to go around, and follow after [more plants] and it changed the sampling method because there are other types of plants [that were flowering] which are widespread [...]. There are many more [flowering] thistles and on thistles it is impossible to wave [the net as it would tear it apart] so we discovered by chance that it was possible to easily catch [the bees] if we simply “jump” [the net] over the bees [grabbing the net at its upper end and waiting for the bees to fly in]." [Ayala, 2nd year Ph.D., field observations] (See Figure 6 for images of bee netting amongst the thistles).

Finally, students adopted a FD position when they changed their sampling method to accommodate weather conditions, so that, as Gal in his 1st year of Ph.D. studies mentioned that "all of the sampling sets will be covered"; this means that the protocol which outlines a given schedule is often extended during bad weather.

As noted previously, my subjects are often plagued by the tough physical conditions of working outside. When challenged by such conditions many of the students responded in a PD fashion by simply stating that "there was no alternative" because it is impossible to control the environment and so they endured rough conditions to complete their research. Some however adopted a FD solution by using
assistants who could shoulder some of the field research (even though the use of assistants adds a different set of challenges).

*Time management* is also critical during field seasons. Unlike lab protocols, which are (more liberally) scheduled based on equipment and variables that can be strongly manipulated and controlled, working in natural environments makes it impossible to predict how much of an experiment can be implemented in a field season. Thus, beginning novices commonly expressed a PD strategy regarding time management:

"The field is like that, time passes by 'in a snap’ […] There were a lot of sites and I couldn’t manage all of them […] I don’t even have enough time to sample the sites I wished to complete at that time.” [Gal, 1st year Ph.D., interview].

In other cases, some of the students relied on an INT strategy in which they flexibly changed their original plan in order to adjust it to the field conditions available:

"The plant sampling took longer than I expected, as there was much more flowering than before. [...] So, I re-planned my fieldwork to maximize my work capacity – I arrived earlier at the field and used the dark and cold hours (when the bees are absent) for plant sampling." [Ayala, 1st year Ph.D., field assessment report].

Another version of an INT strategy concerning the *time management* in the field included the students receiving periodical sampling assistance from their (non-student) friends, or family members permitting them to adapt to a tighter time frame. Our observations showed that most of the students in the research group relied upon such informal sampling assistance.

Finally, some students adopt a FD strategy in which they requested funding for permanent professional assistance for parts of each field season based on the understanding that the sampling could not be completed without such assistance:

"What happened this year [working in the field alone] was not possible. I need to go out to the field with a crew. This is something I have to settle with my two advisors, to have the funding, I don't care how. [...] I can't rely on a project student who will be with me for one sampling [session] because it's not serious. I need permanent people who will be there.” [Ayala, 1st year Ph.D. interview].
The most critical issue following a field season was analyzing data sets consisting of a huge number of interconnected variables in order to test the research proposal’s hypothesis. This difficulty in explaining the many variables is a major challenge as such data sets are often beset by unexplained variance. Gal, (one of two Ph.D. students) is an example of a student who incorporated all three strategies as he progressed through his research in order to cope with this challenge. In his 1\textsuperscript{st} year of research he relied on a PD strategy in which he thought of giving up on his designated site as it was considered inappropriate:

"After entering all of the observations almost all [of the bees] were honeybees. There isn't really a reason to continue with this type of crop [almonds] because it doesn't meet the expectations. There are no wild-bees there." [Gal, 1\textsuperscript{st} year Ph.D., interview].

In the 2\textsuperscript{nd} year of his Ph.D. after acknowledging that his research must continue with the field conditions at hand, Gal adopted an INT strategy in which he changed his sampling strategy (which in this case involved changing the spatial pattern):

"We changed the methodology because we saw there weren't [enough] wild bees amongst the almond crop. […] In the beginning we thought only on big scales, bees at radius of 1.5 km. Now we also think about smaller scales. This means that what happens on the scale of 100 and 500 meters is also important." [Gal, 2\textsuperscript{nd} year Ph.D., interview].

Finally, as a 3\textsuperscript{rd} year Ph.D. Gal implement a FD strategy when he understood that key variables were not included in his initial protocol’s sample. Thus, he added the variable ‘habitat type’ to his protocol, which examined rural vs. agricultural areas in order to explore more deeply into the reason why wild bees were so scarce in almond crops.

The second major set of challenges reflect the fact that the field research setting isolates the students from authoritative support, forcing them to take independent decisions which leads to the mental, technical and professional challenges of working mostly alone. In response, inexperienced novices assume a PD strategy by strongly relying on their advisor’s advice. For example, I observed that Uri, a 1\textsuperscript{st} year M.Sc. candidate, regretted the fact that his advisor Yifat was "not present in the field" as he "didn't have the confidence" to change the protocol that she
designed about where to set the sampling traps. Thus, he just continued with the original sampling plan.

Implementing an INT strategy the students still looked for direction but also applied their own (sometimes) common-sense knowledge to the situation:

"I have a lot of considerations here because I am alone. […] Yifat [the advisor] tries very hard to be available, but she is only available part of the time, not all the time. Then I solve things with common sense but you know because they are small things like yes or no for preparing the sampling but for big things it's not enough." [Ayala, 1st year Ph.D., field observations].

With more experience the students sometimes took a more independent, FD approach to field work:

"This year I feel more independent in making decisions in the field; [where] in the past I consulted with Yifat, [now] I accept decisions alone about whether to sample in a specific type of weather, what to sample, where to sample, whether to move onto another site." [Gal, 2nd year Ph.D., observations].

Another balancing agent to this isolated research setting is the fact that as most of the students conducted fieldwork on bees they were members of a community of practice (Feldman, Divoll & Rogan-Klyve, 2009) that studies the same subject and employs similar methods; this means that they could advise and help each other as they progress through their research. So, even students who conducted most of their field research alone, got the chance to practice the basic methods of field research with other, more experienced, students before they began their first sampling season, as Tidhar, a 1st year M.Sc. student remarked (in an interview):

"Yifat [the advisor] is the ‘‘what to do’’ and Gal [a Ph.D. student who works in the same geographic area, as well as with the same methods as Tidhar] is the ‘‘how to do’’. […] From Gal I learn about how to work in the field like when we were together a whole day in the field as if we were sampling [i.e. they practiced sampling together]. […] I really did [with Gal] one by one, just like what I do every day when I go out for sampling. […] I consult with Gal from time to time on the phone, whether I should do this first and then the other."

However, fieldwork can become too complex and even overwhelming for one researcher, and thus he/she requires the help of research assistants. This imposes the challenges of choosing appropriate assistants who need to be trained and effectively
deployed in the field; moreover, their sampling practices may be subjectively different, causing unexplained variance. Confronted by these subjective differences students cope by applying a PD strategy in which they noticed how their assistant(s) differed in their sampling practice, and simply ‘lived’ with these differences (hoping that they wouldn't make a difference in the results).

An example of an INT strategy was presented by Ph.D. student Ayala who noticed her research assistance’s tendency to sample specific bee species on specific plants (which she explained as being easier to sample). Her strategy for reducing this selective sampling included her own sampling to be more directed toward the more complicated species of bees and plants:

"I try to balance their sampling. I have no doubt that there is a variance, just by them (the assistants) being there (in the field), their sample was much more focused on honeybees and on Taily Weed (a common plant species in her research area) so I sampled everything else and avoided honeybees and the Taily Weed." [Ayala, 2nd year Ph.D. student, interview].

Finally, a FD strategy involved taking an informed decision (as a consequence of previous experience) about whether to include within the research protocol the provision for research assistants:

"I entered part of the results [into the computer from sampling] in the almond plants, and you can see: [the sampling] from this year, in 2010, when there were many research assistants, and each one of them worked a few days here and a few days there without any order. The coding really wasn’t ordered, and I needed to reconstruct [what went on]. […] I need, a maximum, from my point of view of one or two [assistants] that will be there all the time, but if there will be many people, it [the data] can be completely lost. It’s impossible to follow after what each one [of the assistants] is doing. […] But you certainly need to really make sure that you know what a research assistant does, to check him/her, to make sure. You also need to check yourself, that you directed the assistant in a proper way, that you didn’t miss something." [Gal, 3rd year Ph.D., interview].

This longitudinal analysis might give the impression that the use and development of the three strategies is confined to a linear continuum from PD to FD. In fact my analysis (as illustrated in Figure 7) shows the implementation of these strategies is more complex than the student simply being more flexible about adapting
towards increasing contingencies, based on greater experience. Rather, a true, expert ecologist, based on deep understanding of specific situations knows that sometimes it is crucial to maintain a protocol. In other words, with greater understanding of the field and the scientific importance of the questions asked by the protocol, the expert intelligently chooses to be what I call PD\textsubscript{2}, rather than INT or FD. Thus, increased flexibility towards the protocol is not always a sign of developing expertise.

Figure 7: A schematic illustration of how graduate ecology students implement coping strategies (PD=Protocol Dominated; INT=Intermediate; FD=Field Dominated) as they develop increasing research expertise.

Yifat, the advisor of this group, was well aware of this flexibility problem as she noted (in a 3\textsuperscript{rd} year interview):

“I am also scared of excess confidence because […] the protocol is not something that was just made out of nothing. I would be very cautious with such flexibility. […] This [flexibility] is a danger from the perspective of the reliability of the data. Thus, this is a sensitive game, between being slightly flexible and to know where to relax, and where to say O.K. the research won’t fail but I need to go home.”

Thus preserving the protocol (PD\textsubscript{2}) can also be an important (expert) strategy when it is done with intelligent choice rather than algorithmically as novices do. For example, in the 2\textsuperscript{nd} year of his Ph.D., it became clear to Gal that he should sample his plot separately over two days. When asked whether that was the correct thing to do (rather than concluding the sampling in one day), Gal answered: "It's fine. That's what we have". This can be interpreted as a simple (or novice) PD strategy as Gal was simply trying to implement the initial protocol (that was planned before arriving to the
field). What he could not manage in one day, because of the existing weather conditions, he left for another day. However, Yifat, his advisor, who was also part of this conversation (in the field), gave another perspective to Gal’s strategy which in fact represented an intelligently chosen PD$_2$ strategy:

"It [the sampling] should be spread out as much as possible. Indeed, if we could have done all of the plots like this it would have been better. Because if it is a cloudy day and you conduct a morning sampling, it would be better if the second sampling was conducted in the afternoon of an other day that is not cloudy [Note that the students generally conducted two samplings every day: morning and afternoon]. But technically it is difficult with all the traveling needed in between plots. It's unique to field research [in contrast to lab-research] as we are at the mercy of the weather conditions".

Although the result of using a PD1 or PD2 strategy is the same, the reasoning behind it is very different. Yifat's comments about Gal's actions in the field acknowledge that a protocol asks important scientific questions that should not readily be abandoned.

**Motivation**

The last, but certainly not least important learning component for doing field-ecology research is motivation. Indeed, Sternberg (1999, p. 364) argues that motivation drives the other elements of his developing expertise model: ‘motivation is perhaps the indispensable element needed for school success. Without it, the student never even tries to learn’.

Research on student motivation distinguishes between *intrinsic* and *extrinsic* motivational orientations, which differ in their underlying attitudes and goals that give rise to action. *Intrinsic* motivation relates to mastery and task-involved orientations and refers to doing something for its inherent satisfaction, whereas *extrinsic* motivation relates to performance and ego-involved attitudes and refers to doing something because it leads to a separable outcome (Pintrich, Marx & Boyle, 1993; Ryan and Deci, 2000; Sternberg, 1999). In the following discussion I will address these motivational orientations that both encouraged and discouraged my subjects when implementing their field research.
An intrinsic motivation refers to doing an activity because it is inherently interesting or enjoyable, rather than because the student received external pressure or rewards (Ryan and Deci, 2000); this was very dominant in my subjects' attitudes toward their research. The most common intrinsic motivational factor for my subjects was expressed by their answers to the question: "what motivated you in your field ecology research?" In fact, 10/12 subjects surveyed mentioned their inherent interest for applied ecological field research.

In discussing (intrinsic) motivation for academic learning, Alexander’s (2003a) MDL distinguishes between individual and situational interests. She refers to individual interest as the enduring investment in a particular domain, while situational interest as a fleeting arousal of attention stimulated by events in the learning environment. Accordingly, my subjects' interests can also be distinguished with these motivational types.

Their individual interest was expressed in the subjects' curiosity towards "the domain of ecology"; "ecological research"; "plants and nature"; "how animals and plants interact in the field" (as noted in their interviews). A detailed example of this individual interest in applied ecological research is also found in the questionnaire answer provided by Uri, a 1st year M.Sc.:

"For me, applied ecological research is a personal interest. I believe in conducting applied ecological research which provides techniques and modes of action. The situation with an ecological habitat is that it has substantial information that includes many layers of knowledge. For me, this [applied] approach is more interesting in contrast with the regular approach [i.e. a theoretical approach] that we are doing today."

The subjects' situational interest was exemplified when they asked particular questions in relation to their field-research surrounding. For example, Ph.D. student Gal wondered while working in the field "what would happen with the wild-bees activity at the almond plants, once there would not be any honeybee hives in the area." Although, this was not one of his research questions, Gal found that particular environmental situation "a very interesting question" [Gal, 1st year Ph.D., field-observation].

Another intrinsic motivational factor which is connected to task-involved orientations can be found in the students' belief in their own research implications on solving environmental problems and its contribution for nature conservation. 6/12
students mentioned this as a motivation component in the questionnaire, such as Hadar, a 2nd year M.Sc. student:

"Nature conservation is the most important incentive for my research. When I began my degree, it was very important to me to find a subject that tested man’s influence on the natural environment. […] For the most part, that is the source of my motivation."

Promoting nature conservation as a task-involved motivation for pursuing field-ecology research was also evident in the subjects' interviews. For example, (Ph.D. student) Ayala referred in her 1st year interview to the importance of her research by "designing a tool for the Nature and Parks Authority which can assist their decision making" which in turn motivated her research practice to be as accurate and as significant as possible.

Other then interest and task-involved orientations, **intrinsic** motivation, as mentioned previously, is defined as connected to experiences that are inherently enjoyable (Ryan & Deci, 2000). This characteristic was seen in the subjects' feelings of pleasure of working in nature. This motivational element of enjoying working outdoors was mentioned by two subjects in the questionnaire as well as in the interviews and observations. For example, Ph.D. student Ayala mentioned on her 1st year interview:

"There were a few days when I was working during the peak of flowering for the acacia trees. It was insane […]; clouds of butterflies surrounded the acacia trees, millions of them. It's like you look at it and you are in a total spiritual high. […] It's a very moving experience."

In fact, all five subjects answered that working in the field is more enjoyable than working in the lab (which was mentioned in their first and last interview). In fact, this feeling was not restricted to the students, as the advisor of the group, Yifat, also noted in her 1st year interview that:

"On the days that I go out to the field, I love it, it's enjoyable. It's kind of an in-between trip and work."

In contrast to the inherently **intrinsic** motivation which promotes personal satisfaction (Ryan and Deci, 2000) or task-involved orientations (Pintrich, Marx & Boyle, 1993) **extrinsic** motivation is driven by instrumental value to some separable consequence (Ryan and Deci, 2000) as well as by performance and ego-involved orientations (Pintrich, Marx & Boyle, 1993). **Extrinsic** orientation was expressed by
my subjects' motivation for implementing their field-ecological research in two ways. The first was through their wish to complete their research, as was noted by two students in the questionnaire, one of them being Ph.D. student Ayala:

"When field conditions are tough, my motivation are to just get enough work done so at least I will get a Ph.D. out of it."

The other way that extrinsic motivations were expressed was via the students' desire for professional progress. This was mentioned by three students in the questionnaire as well as during interviews:

"I would really want to work in some kind of an environmental organization [...] or even to direct the environmental and ecological aspects of an organization, maybe in planning committees as an ecological professional. But these positions are usually for people at a higher level of (academic) background; [a] masters is not enough, but it's a start." [Uri, 1st year M.Sc., interview].

These intrinsic and extrinsic orientations drove the students to acquire different types of knowledge (declarative and procedural) which enabled them to develop the skills needed to conduct their specific research. However, as described before, learning to conduct field research is complex for researchers at all levels of experience, which can very easily cause them to feel discouraged and thus incapable of performing the research. This complexity is due to the uncontrolled nature of the field and the isolation that the students (sometimes) feel working, independently.

With regards to the uncontrolled nature of the field, the students often mentioned the struggle to reduce the (independent) variables in the experimental set up, which made them feel as if they were at the mercy of unexpected, natural change:

"Conducting field research is much more complicated (than lab-based research) because you need to think about many variables, you cannot control the (research) system like you can in a laboratory. So a lot can go wrong. It can be very frustrating." [Hadar, 2nd year M.Sc., interview].

Working independently, isolated from authority can also discourage the students' motivation. Not only do they worry about making the wrong decision when facing unanticipated challenges, or technically not handling all of their sampling by themselves, but also they fear for their safety or feel lonely when spending many hours alone. For example, 1st year Ph.D. student Ayala talked about inviting her
boyfriend or her father to a fieldwork session to avoid her mental challenge of working alone:

"The loneliness can drive me insane. So, one day Oren (her boyfriend) came with me, and in another day my father came along. There's a great difference between working alone and with someone else, it doesn't even need to involve physical assistance; my father is not a big expert in sampling bees, but the interaction with another person is so nice. In a great deal, it's good to have someone to share your frustrations with; it's easier. When I am completely alone in the field, it can make me crazy; hour after an hour, it can be very boring on your own."

Interactions between the learning components

Each of the learning components (Knowledge, Skills, and Motivation) mentioned above are essential on their own for becoming a field-ecology researcher. However, as stressed previously by Sternberg's (1999) "developing expertise model" as well as by Alexander's (2003a, 1997) "model of domain learning" (MDL), comprehending the interactions between learning components permits a fuller understanding of the learning process. Figure 8 below is a schematic diagram of the interaction between learning components needed for conducting field-ecology research. Note that these interactions refer to all three stages mentioned in the field ecology scheme shown in Figure 1 (Planning, Applying and Analyzing).

Figure 8: Interactions between the learning components needed for implementing field-ecology research.
According to the models of Alexander (2003) and Sternberg (1999), respectively there is a bi-directional interaction between knowledge and skills. On the one hand, students' ability to apply their skills effectively is dependent on their existing knowledge; but also, in implementing their skills, the acquisition of knowledge is enhanced.

In the case of conducting field-ecology research, both declarative and procedural knowledge were crucial for the students' ability to develop the research skills that permitted them to cope with the different challenges of their field-research; nonetheless, these two forms of knowledge differed in how they were acquired. In contrast to the nicely packaged declarative knowledge gleaned from coursework and research literature, procedural knowledge was largely gained via the daily, situated experience of implementing research in complex field environments:

"As for theoretical [declarative] knowledge, it gave me a good initial background and contributed in that I know what information I need to collect and how I will analyze the data, generally. I am sure that someone who learns many courses in ecology during their undergraduate degree understands much easier this type of research than someone who learned more molecular [biology]. But nonetheless, the big part of the experience that assisted me in research was accumulated during my field experience." [Hadar, M.Sc. student, questionnaire].

Although not as course-based as declarative knowledge, some students did mention that their procedural knowledge was partly learned in a few (undergraduate) research courses and projects which prepared them to cope with the challenges of their graduate field-research, as was noted by 3rd year Ph.D. student Ayala:

"The contribution of the research project (experienced during her undergraduate program) was that it required independent thinking and the need to cope with problems on your own. Definitely, the practice improved (my) achievements."

However, gaining such experience takes time and most students started their research with little research-based procedural knowledge; this means that they could not always react flexibly to daily fieldwork challenges and their research suffered, which in turn negatively affected their motivation. This lack of motivation adds to the insecurity and lack of confidence that already existed amongst some of the students.
due to the fact that they must independently cope with the unexpected nature of field research.

However, sometimes research challenges can also spur students towards a search for greater knowledge sources which results in the students also acquiring the field-related skills needed for coping with research complexity. This experience of handling the challenge, in many cases, independently, or just being aware of it can have a positive effect on their extrinsic motivation. This positive effect was expressed by the students by the fact that they knew better what (specific) abilities were required of them to successfully conduct their research:

"I didn’t have a lot of experience in [...] sampling insects before this, although I helped [other students] in the field, but it [their field] was quite different from mine. It did prepare me to do field work and what can be expected from it – sometimes a succession of working a couple days or weeks away from home, and being outside in the field all day in desert-like heat can be mentally exhausting; and it seems to me that because I knew what to expect it made it easier." [Hadar, M.Sc. student, questionnaire].

Furthermore, Alexander (2003) indicates the importance of goal-oriented motivation for pursuing knowledge and employing strategies in a specific domain. Thus, one of the factors that might enable the students to overcome the daily challenges of field-research was their intrinsic motivation. A prominent example of this intrinsic motivation was reflected in the students' conspicuous interest in the subject of field-ecology. Such interest encouraged students to acquire the (mainly procedural but also declarative) knowledge necessary for developing research skills (exemplified by the use of the three metacognitive coping strategies) in order to cope with field complexity. Such motivation is more than just responding to the basic need for obtaining knowledge to solve a research problem; rather, it cuts to the identities of the students and their inherent beliefs in their research rational and its implications.

4.3. Goal 2: Comparing the process of expertise acquisition of M.Sc. vs. Ph.D. students in field-ecology research

In order to gain a deeper perspective on the development of research expertise amongst graduate field-ecology students, in this second part of my thesis I will longitudinally compare the development of M.Sc. and Ph.D. students as they learn the expert competencies needed to pursue independent research. Based on my previous
characterization of the learning environment of field ecology research, the specific parameters that I use to compare this development are the **challenges** that these students confronted, and the different coping strategies they adopted in order to overcome said challenges.

The comparison of these parameters is based on data triangulated from the qualitative instruments of this study (interviews, observations, field assessment reports and questionnaire) as well as quantitative data that was transformed (via frequency counts) from the qualitative field assessment reports. I will compare these parameters by answering research questions 2a and (later) 2b:

**Research question 2a:** How do the specific **challenges** of conducting research in field ecology change in importance in the view of the M.Sc. and Ph.D. students as they gain research expertise?

The comparison of the challenges experienced by the M.Sc. and Ph.D. students, respectively is based on my analysis of the challenges presented in the coding map illustrated in figure 3 along with the quantitative frequency counts of the challenges mentioned by students in their field assessment report (Table 1). (Note that three challenges mentioned in the previous qualitative coding map were not common in the students' field-assessment reports and so were not part of this quantitative analysis. These challenges are "mental pressure" and "technical challenges" associated with "working alone" and the challenge of "choosing appropriate assistants" associated with "working with research assistants").

With regards to challenges connected to **environmental conditions**, Table 1 shows opposite trends between M.Sc. and Ph.D. students; in the former cohort there is an increase in such challenges from their 1st to 2nd research years, whereas in the latter cohort there is a decrease from the 1st to 2nd years. Correlating these finding with my qualitative analysis suggests a number of factors that might account for this difference. M.Sc. research is conducted over a relatively short time-period (2-3 years) by students who implement a research protocol mostly designed by their advisor; thus, in their 2nd and (usually) final sampling year they are pressured to conduct successful research; the added complexity of uncontrolled environmental conditions can affect their ability to collect enough data from the field, as was mentioned by Hadar, a M.Sc. student who was then in her 2nd year of research:
"I find it both funny and sad that the district beekeeper (in her field-research area) told me that this year is not good (for flowering) so I should come next year. I need to finish my M.Sc. this year!" [Hadar, 2nd year M.Sc., field observation].

In contrast, the Ph.D. students were observed to be more independent from the beginnings of their research, which means that environmental conditions weighed more heavily upon them as they tried to coordinate their research protocol with the field conditions. For example, Gal's Ph.D. research was conducted on agricultural land, and already during his 1st research year he talked (in an interview) about the importance of coordinating his schedule with the flowering season:

"The flowering is supposed to begin in May but I must be in touch with the farmers to make sure that the flowering will not start [early] at the beginning of April and I will not be updated."

However, by their 2nd year, with experience in the field and a better developed expertise, the Ph.D. students learned to anticipate the fact that environmental conditions change unexpectedly. Having another sampling season ahead of them (in their 3rd research year), their awareness of such change helped them to prepare their research protocol so that it was adaptable to different environmental conditions, as noted by Ayala, a 2nd year Ph.D. student, while she was working in the field:

"The change in weather conditions from last year to this year caused extreme fluctuations in flowering and bee activity. This [actually] makes me feel OK because next year I will know better how to be prepared. [...] You can always be surprised in the field but [by being aware of a challenge] you can cope better."
Table 1: Yearly frequency change in research challenges as mentioned in the field assessment reports (N=31) by M.Sc. and Ph.D. ecology students (N=5).

<table>
<thead>
<tr>
<th>Research Challenges</th>
<th>M.Sc. 1st yr (%)</th>
<th>M.Sc. 2nd yr (%)</th>
<th>Ph.D. 1st yr (%)</th>
<th>Ph.D. 2nd yr (%)</th>
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<td>21.1</td>
<td>15.6</td>
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<td>23.1</td>
<td>10.5</td>
<td>6.3</td>
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<tr>
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As for the research methods challenges, applying specific methods and tools in the field was a challenge for all of the graduate students. However, there were differences between the two cohorts. For 1st year M.Sc. students implementing methods and tools is the single greatest problem (nearly half of all reported 1st year research challenges, as seen in Table 1) with a subsequent large decrease by their 2nd year of study. In contrast, the Ph.D. students show an increase in this challenge from their 1st to 2nd research year. These trends represent the fact that Ph.D. research acquires increasing complexity as new methodological experiments are added after the 1st research year, whereas the M.Sc. students continued with the protocols that were designed with their advisors strong input. These differences were supported by the interviews with Ayala (Ph.D. student) and Uri (M.Sc. student), respectively who were then in their 2nd year of research:

"At the end of the last [sampling] season, when I saw the conditions in the field, and that in fact I need more information [than were provided by methods I used] I realized I need other experiments. [...] The methods used in the additional experiment are very new to me, I will have to learn
and experience them before I can say I know them. It's not that easy, as I need to learn and implement it in addition to the methods I used last year." [Ayala, 2nd year Ph.D., interview].

"On this sampling season I felt much better in knowing the field. [...] When you are in the field for the first time you need to learn how to handle the new methods, it's hard. But now, that I am using the same protocol and the same methods it's very basic, not complicated." [Uri, 2nd year M.Sc., interview].

These differences between M.Sc. and Ph.D. students correlate well with those suggested by Feldman, Divoll and Rogan-Klyve (2013, p.234) concerning the different levels of 'methodological proficiency' exhibited by these two cohorts, respectively. In their study, M.Sc. students used known methodologies in order to manage their research, whereas the Ph.D. candidates had an additional ability to innovate and develop new methods. So too, in my study, the Ph.D. students in their 2nd research year found it necessary to both use and develop new research methods; this of course was more challenging for them as they were not simply repeating and managing their research methods like the M.Sc. subjects.

The different levels of 'methodological proficiency' between Ph.D. and M.Sc. students could also be the reason for the differences in the students’ reports on the specific challenge of time management. As typified by Uri’s quote, above, in the 1st year of M.Sc. research, the students needed to learn how to implement their protocols in the field and so it was more challenging for them to manage their time effectively than in their 2nd year of practice; indeed, none of M.Sc. candidates reported the challenge of time management in their assessment reports (Table 1).

For the Ph.D. students, the challenge of time management was reported in their 1st research year at a higher frequency than the M.Sc. students, with only a minor decline in their 2nd year. This trend could have been caused by the fact that in contrast to the M.Sc. students who in their 2nd year of research only repeated the protocols of their previous year, Ph.D. students were required to implement additional experiments in their 2nd year of research which also needed to be coordinated them with their previous experiments; this challenged their ability to manage their time.

The final challenge connected to research methods, is unexpected field variance (or 'environmental noise') which showed similar trends between the M.Sc.
and Ph.D. students (Table 1). Both cohorts reported a decrease in this challenge from their 1st to the 2nd research year which could be explained by the students learning to understand the limitation of their field-based research. However, in both years, the Ph.D. students still reported this challenge in higher frequencies than their M.Sc. counterparts. This could be explained by the fact that the M.Sc. students largely received their protocols from their advisor who anticipated some of this variance, based on her fieldwork experience. However, the complex research design of the Ph.D. students which is enhanced by their need to pursue independent research from the beginning of their studies prompted their immediate concern with fundamental issues such as unexplained variance. Uri, a M.Sc. student referred to this difference between the two cohorts in his 2nd research year:

"In my research Yifat [my advisor] pretty much designed the research protocol and I didn't contribute that much to it. [...] I didn't deal with the statistical thinking [at the beginning of the research] and she basically told me how she thinks it should be done, as I didn't know. This is how it is usually in an M.Sc. [...] In a Ph.D., I am sure the student has more say in the planning of the research as he takes it in the direction he wants. [There is] more independence in that manner. It's a big difference."

Connected to this issue of independence when working alone in the field, is the fact that the M.Sc. students were challenged by the professional challenge of making independent decisions; indeed this challenge remained constant for the M.Sc. students during the period that they were monitored via the assessments. The fact that the M.Sc. students’ fieldwork period is short and supported by their advisors means that they are less tested by the field and thus aren’t pushed as hard to develop the same level of independence and self-discipline seen in Ph.D. students; as we saw above, Uri, one of the M.Sc. students, admitted as much. Accordingly, Ph.D. students did not report independent decision making as a challenge in their assessment reports either in their 1st or 2nd research years.

This general challenge of conducting independent fieldwork also correlates well with the academic level (i.e. experience) of the students and the consulting sessions they had with their advisor. Based on data collected with the assessment sheets I found that in their 1st and 2nd years of research M.Sc. students reported overall consult frequencies (= Total number of consults/total number of coping strategies) of 83.3% and 46.2% respectively; in contrast, Ph.D. students were significantly more
independent, reporting frequencies of 15% and 18.5% respectively in their 1\textsuperscript{st} and 2\textsuperscript{nd} years of research. These findings were supported by the students' advisor, Yifat, when she compared how her guidance differs between M.Sc. and Ph.D. students, respectively:

"It [my guidance] is different between M.Sc. and Ph.D. students. M.Sc. students are more like 'sub-contractors' whereas doctoral students already have their own agenda and are supposed to have more understanding of the system as well as experience [...] more mature. [...] When I talk with a doctoral student I know he has more experience than me in his research model, so we discuss things together. M.Sc. students are usually inexperienced, so I try to pair them with a doctoral student and my guidance is much closer." [Yifat, Advisor, 2\textsuperscript{nd} year interview].

In her comparison of Ph.D. and M.Sc. students, Yifat is presenting a perception common to many academic advisors as reported by Feldman, Divoll and Rogan-Klyve (2009). In their study of five university research groups, they showed that the Professors had distinct expectations of what their respective M.Sc. and Ph.D. students could accomplish. M.Sc. students were expected, by the end of their studies to attain the knowledge and skills necessary to become skilled practitioners (or "Proficient Technicians") in their discipline, whereas doctoral students were expected to become "Knowledge Producers" who are able to formulate their own research questions, to develop new research methods, and to add to the literature.

In analyzing how the students coped with research challenges, it became evident that an important part of their coping strategies involved consulting with their advisors, which more often occurred via phone, rather than through direct meetings as they were conducting research in the field. Such consultation between student and advisor shows that the research team is embedded in a (larger) community of practice (Knorr-Cetina, 1999; Lave & Wenger, 1991). Additionally, in receiving feedback and assistance from their advisor who both model and evaluate their performance, the students are participating in what Collins, Brown, & Newman (1989) refer to as a cognitive apprenticeship.

Analyzing the topics of student-advisor consultation sessions and correlating them with challenges (Table 2) provides greater validity to my previous analysis of the specific challenges experienced by the graduate students in pursuing fieldwork (as seen in Table 1).
Table 2: Yearly frequency change in consults correlated with specific research challenges as mentioned in the field assessment reports (N=31) by M.Sc. and Ph.D. ecology students (N=5).

<table>
<thead>
<tr>
<th>Research Challenges</th>
<th>Consult Reports</th>
<th></th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>M.Sc. 1\textsuperscript{st} yr (%)</td>
<td>M.Sc. 2\textsuperscript{nd} yr (%)</td>
<td>Ph.D. 1\textsuperscript{st} yr (%)</td>
</tr>
<tr>
<td><strong>Environmental Conditions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncontrolled Nature of Research</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental</td>
<td>Research Plots</td>
<td>0</td>
<td>23.1</td>
</tr>
<tr>
<td></td>
<td>Weather</td>
<td>0</td>
<td>30.8</td>
</tr>
<tr>
<td></td>
<td>Physical conditions</td>
<td>10.5</td>
<td>7.7</td>
</tr>
<tr>
<td><strong>Research Methods</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Applying methods/tools</td>
<td>52.6</td>
<td>15.4</td>
<td>20.0</td>
</tr>
<tr>
<td>Time management</td>
<td>10.5</td>
<td>0</td>
<td>15.0</td>
</tr>
<tr>
<td>Unexpected variance</td>
<td>10.5</td>
<td>7.7</td>
<td>5.0</td>
</tr>
<tr>
<td><strong>Research setting</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working alone</td>
<td>Making independent decisions (Professional challenge)</td>
<td>15.8</td>
<td>15.4</td>
</tr>
<tr>
<td>Working with Research assistants</td>
<td>Training / Employment</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Subjective sampling</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Applying field methods and tools were the single largest reason for a consult amongst both the Ph.D. and M.Sc. students. Especially amongst the 1\textsuperscript{st} year M.Sc. students, methodology is a huge concern as they literally come into their graduate programs from their undergraduate degrees with very little situated knowledge of applying methods. Thus, although they receive liberal amounts of support from their advisor in designing their protocols, they also need much support in implementing or changing them when needed. This also appears to influence the pressure that the M.Sc. students felt in that they must do the research properly in the short time allotted.

Such time pressure also affected the M.Sc. consults connected to environmental conditions; in the 2\textsuperscript{nd} research year consults connected to research plots and weather largely increased. With the 1\textsuperscript{st} year devoted to designing and implementing their initial protocols, there is tremendous pressure in the 2\textsuperscript{nd} year for the students to neutralize (and explain), as much as possible, weather effects and poor plot conditions. In contrast, Ph.D. students were more concerned with environmental
challenges in their 1st research year. Ph.D. students are largely responsible for designing and implementing their protocols from the beginning of their programs, so for them there is a need for consult in order to negate interfering environmental factors immediately.

This difference in how the M.Sc. and Ph.D. student reacted to environmental change was reflected when it became difficult (to impossible) to find research plots due to extreme environmental conditions; M.Sc. student Hadar, who understood that she could not afford the wait (for the conditions to change) consulted immediately with her advisor:

"I could not find enough [research] plots in the field and it all seems so uncertain, everything is so dry now, [...] there are too many things I can't control. The truth is I consulted with Yifat [the advisor] and we decided I will do a different experiment, from a very different point of view - to sample bees in natural areas before and after adding honey-bee hives [...] I think this can give me an answer, it's more focused and maybe I could finish my research on time." [Hadar, 2nd year M.Sc. student, Interview].

In contrast, Ph.D. student Ayala, who's field-research was located in the same surrounding as Hadar, and was challenged by similar environmental changes from her 1st to 2nd year made the coping decision (of finding new plots) on her own and only later reported this change to her advisor, as she mentioned in a 2nd year interview: "I have updated Yifat [and] she knows".

As their work is more complex, due to the larger number and variety of experiments they conduct, as part of their research setting, the Ph.D. students also tend to rely on assistants, who must be correctly trained, deployed and monitored to prevent unexplained variance due to sampling errors. This means that they often needed to consult with their advisor who has greater experience directing large-scale research. Such concerns did not affect the M.Sc. students whatsoever, as their research tends to be smaller-scale and so is usually conducted alone without the use of assistants.

These findings about challenges and the resultant consultations indicate some strong trends amongst the M.Sc. and Ph.D. students, respectively, on how they reacted to their research. As mentioned in the previous section of my results, many of the challenges which the students faced were due to the gap that existed between the
idealized protocols and the reality of complex field conditions that they discovered when they entered the field. In order to longitudinally track the development of the students' strategies for coping with this challenging "protocol-field gap", I asked the following research question:

**Research question 2b:** How does the usage of different coping strategies to solve research challenges in field ecology change as the M.Sc. and Ph.D. students gain research expertise?

To track these changes I used each of the three metacognitive coping strategies (protocol-dominated (PD), intermediate (INT) and field-dominated (FD)) which the students adopted for dealing with the dynamic tension that existed between their idealized research protocol and the reality of field conditions.

Similar to my discussion of the previous research question, comparing the M.Sc. and Ph.D. coping strategies also involved triangulating the qualitative coding of the coping strategies with the quantitative frequency counts collected via the field assessment report through their first two research years (Table 3). Please note however that the (advisor's) PD2 strategy discussed in the previous section (which emerged from field-observations and interviews with the advisor) was not found in the students' field-assessment reports, and therefore is not apparent in this quantitative analysis.

Overall, the frequency counts presented in Table 3 show a great difference between the coping strategies adopted by the M.Sc. and Ph.D. students. The M.Sc. students were PD in both years of their studies, and thus generally showed a lack of flexibility towards making full changes in their research plans. In contrast, in their 1st research year, the Ph.D. students were balanced in their adoption of the three strategies, whereas in their 2nd year there was a strong shift towards greater flexibility as represented by the FD.

These frequency differences between the two cohorts can be explained by the way in which they relate to their protocols. M.Sc. students are expected to complete their research in a short time frame; moreover, their research is directed towards a finite problem suggested by their advisor. Thus, M.Sc. students trust their advisors to provide them with a protocol requiring little improvisation. Also, in their undergraduate experiences adhering to a protocol dictated by a typical laboratory
course insured that they obtained good results. Delamont and Atkinson (2001) testify to a similar situation with graduate geology students. Simply put the M.Sc. students' attitude towards the protocol binds them to its dictates.

**Table 3**: Yearly frequency change in coping strategies as mentioned in the field assessment reports (N=31) by M.Sc. and Ph.D. ecology students (N=5).

<table>
<thead>
<tr>
<th>Coping Strategy</th>
<th>M.Sc 1(^{st}) yr (%)</th>
<th>M.Sc 2(^{nd}) yr (%)</th>
<th>Ph.D 1(^{st}) yr (%)</th>
<th>Ph.D 2(^{nd}) yr (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol-dominated (PD)</td>
<td>52.4</td>
<td>66.7</td>
<td>34.2</td>
<td>5.3</td>
</tr>
<tr>
<td>Intermediate (INT)</td>
<td>47.6</td>
<td>33.3</td>
<td>30.0</td>
<td>32.4</td>
</tr>
<tr>
<td>Field dominated (FD)</td>
<td>0</td>
<td>0</td>
<td>35.8</td>
<td>62.3</td>
</tr>
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</table>

Furthermore, my results show that fieldwork complexity, and the changes required to the protocol in order to deal with such complexity were often unclear to beginning students (especially the M.Sc. cohort); however as they gained experience in authentic environments, their responses became clearer, as Tidhar, a 2\(^{nd}\) year M.Sc. student acknowledged:

"I used to think that every small change I made [in the protocol] is critical, and will cause a serious problem. [...] In time, you understand better what you are doing, so you know what is really the chance that this small change would affect anything [...] You just need to minimize the fear about the small deviations you make [from the protocol] and that what you do is not one hundred percent accurate [to the protocol]."

Thus, Tidhar realized that his protocol could be changed, and crucially he was aware that he was unafraid of changing it. These changes at both the affective and cognitive planes of learning mark a crucial stage in developing the expert competencies needed to conduct field research.

In contrast, the Ph.D. candidates received much more responsibility for designing their protocol and needed to be more open towards changing it based on field experiences. These differences between the two cohorts are not only a result of the Ph.D. students having greater field experience; in fact (Ph.D. student) Gal's background was in molecular biology; factors, such as research depth, as well as a general maturity towards doing any kind of scientific research induces a Ph.D. candidate to adopt a field-dominated disposition more quickly.
Interviews and observations also show that M.Sc. students were sometimes overwhelmed by the abundance of field details and therefore miss broader, significant trends. This was one reason that the protocol was so attractive; it seemed to answer these details, but in reality when students began fieldwork, they realized that the protocol missed many details. This frustration was noted by M.Sc. student Uri in his 3rd research year:

"In lab-research the protocols are very clear [...] but in field-ecology it's less clear. There are all sorts of additional factors that you can't control. When you are in the field, you can't really know if your sample really represents the specific season it's supposed to, as the conditions are so different from one year to another. [...] When you are doing an M.Sc. it's critical. There is nothing you can do. You can't really repeat your sampling as your time is up. It's frustrating, that's what it is."

In contrast, the Ph.D. students had much more responsibility in designing and implementing their protocol and understood that it focused on answering higher-level questions. Thus, from their 1st year of research they were aware of the uniqueness of their field-research area as well as how quickly the environment can change and they were not afraid to use their own knowledge to make changes in their protocols and use strategies that shows flexibility to the changing conditions of the field (as INT or FD).

"It (working with the research protocol) is always through trial and error. [...] It (the protocol) is never perfect when you start, because usually you go into a new territory where no man has gone before and it's a matter of a specific field. [...] I think the right way of conducting research in the field is to see what would fit best to your specific field area and the (environmental) conditions it is at that moment. And you can only see that when you are present in the field." [Ayala, 1st year Ph.D., interview].

Overall, my analysis shows that with increased experience (i.e. from M.Sc. to Ph.D. level) students advanced from being strongly protocol-dominated to being strongly field-dominated. To more deeply represent these changes I will draw upon Dreyfus and Dreyfus' (1986) model of skill acquisition, as well as Alexander (2003) and her colleagues (1997) MDL. However, it should be remembered that Dreyfus and Dreyfus is a general expertise model (i.e. not domain specific) and that although Alexander focuses on academic subjects, she does not look at conducting research.
Based on Dreyfus and Dreyfus’ (1986) I place strong PD use at the level of 'novice' or 'advanced beginner'. The former is characterized by a rigid adherence to plans, with little discretionary judgment, and little perception of the situation. The latter is distinguished by a still limited perception of the situation, and where all aspects of the work are treated separately and with equal importance. Moreover, in Dreyfus and Dreyfus’ model, novices (and even advanced beginners) are interested in doing a good job, but as they lack any coherent sense of the overall task, they judge their performance, to a large degree, by how well they have followed learned rules; moreover, such a strong adherence to the rules means that a novice does not grasp when such rules should be set aside, or even maintained (intelligently). Similarly these early stages match well with Alexander (2003) and her colleague’s (1997) “acclimation” stage because such novices knowledge of the system is limited and fragmentary which means that they are unable to apply deep-level strategic (metacognitive) processing.

In the specific case of field-ecology research, the novices (most notably the M.Sc. candidates) were determined to implement the protocol, algorithmically because this was approved by higher authority and it provided a crutch upon which the students could lean when problems arrived. Thus, the protocol was not just a cognitive tool for guiding the research, but also had an affective (or emotional) dimension. As the advisor of this group Yifat is well aware of this dependence she discussed those students who implement the protocol, algorithmically:

"They think that this [the protocol] is something basic, [and] because they [novice students] are supposed to do this, then this is what they are trying to do." [Yifat, advisor, 3rd year interview].

Once they became flexible enough to adapt towards the contingency of the field, the students adopted INT or even FD strategies towards fieldwork. Based on both Dreyfus and Dreyfus’ (1986) and Alexander (2003) and her colleagues (1997) they were passing into stages encompassing “competent” and then “proficient” behavior. In these stages the students' knowledge is more coherent and they adopt deep-level strategic processing. (Note that I grouped these stages together because they are based on a subject’s innermost considerations and it is not usually possible to know exactly why our subjects adopted the strategy that they did).

Another (expert) coping strategy that is important to address regarding the challenges of field-ecology research was termed in my study as PD2 (which was
described in the previous section of my results). This strategy is based on an intelligent decision that in specific situations it is crucial to maintain a protocol. In fact, this strategy was addressed only by the Professors participating in my study (Yifat and Yonathan) and thus can be regarded as a result of developing a higher stage of research expertise. Applying this PD2 strategy exclusively by experts can be explained by Dreyfus' (2001, p. 170) definition of an expert:

'The expert has learned to distinguish those situations requiring one reaction from those demanding another. That is, with enough experience in a variety of situations, all seen from the same perspective but requiring different tactical decisions, the brain of the expert gradually decomposes this class of situations into subclasses, each of which requires a specific response.'

In my study, this strategic decision to maintain a protocol is dependent on knowledge and experience that enables experts to distinguish between protocol's criteria that can be flexibly handled, and other criteria which important for the research and so should not be altered.

This is one of the reasons that both Yifat and Yonathan declared that it was very important for them to know the changes the students were making to their research protocols when implementing them in the field. Changing the protocol can result in significant implications for the students' research, and the advisors who are physically separated from the students' daily fieldwork, would sometimes learn about these changes when it was too late to act upon them:

"In the field every judgment that results in changing your protocol can be fundamental for your research results. The protocol was designed to give boundaries for the individual's judgment calls […] and is based on other experienced people. If you want to change it, according to field conditions, so yes, sometimes you can be more flexible, but you need to think good and hard, and consult about it. I would be very happy if the students would have called me to consult before making any changes, especially the M.Sc. students. […] I can honestly say that I will know about many of the protocol changes that were made when I will read their thesis." [Yifat, advisor, 3rd year interview].
"This is the classic difference between theory and practice. Every advisor says to himself a million times a year- I will go out (to the field) with all of my students, and I will make sure all of their plots are in order. [...] And then, the year goes by and you find out that for 80% of your students you didn't manage it and they did it on their own. [...] and another month goes by and you see the data and you realize that some of the plots were changed and were not sampled properly. It's unbelievably typical."

[Yonathan, advisor, 3rd year interview].

Finally, it seems that one of the factors enhancing the students’ expertise development was their involvement in my research. All of the students explicitly noted that they arrived at insights about their actions due to their participation in my research. These reflections were expressed in each of my research instruments: interviews, observations in the field (where they talked with me and explained their actions), the questionnaire and most notably in the assessment reports. When queried about the effectiveness of the field assessment reports, all of the students mentioned how well the assessments organized their thoughts and enabled them to think about how they solved research problems. Gal, a 3rd year Ph.D. student acknowledged the importance of such reflection while he was conducting field research:

"It [the field assessment report] was helpful in organizing the research; otherwise it's done much later, after the [sampling] season [is over]. When you do it in the field, there is a chance to implement it even in the same season."

Moreover, all of the subjects believed that the assessment reports can serve as an additional communication channel with their advisor, although there were also differences between the cohorts. The M.Sc. candidates coalesced around the practical value of the tool as it can help them “get more assistance from their advisor” (Uri, 3rd year M.Sc. student, interview). This can result in reducing their need to make independent decisions. While the Ph.D. students saw the instrument’s utility for communication, they relate to their advisor as a figure to consult (a research partner) rather than one who dictates. Thus, they also thought of the assessments in a wider context, as a metacognitive tool for focusing their research, as Gal (a 3rd year Ph.D. student) noted in an interview: “It can make you think about the research conditions, the equipment, the research questions”.
5. Conclusions and Implications

This longitudinal study characterizes the learning environment and the development of research expertise of graduate students in the domain of *field-ecology*. It differs from previous studies concerning expertise, such as Sternberg (1999) and Alexander (2003a) and her colleagues (1997) as it focuses specifically on implementing research in a specific scientific discipline. Nonetheless, the learning components (knowledge, skills and motivation) mentioned in these previous studies were used as a theoretical framework in order to define the unique learning environment of field ecology research. In fact, these learning components designated the affordances which enabled the students to learn how to cope with their research challenges. Thus, a preliminary and essential step of my study included the characterization of the challenges connected to conducting field-ecology research.

The situated learning movement, in which my study stands for, argues that deep learning occurs when students activate specific tools while pursuing activities in authentic environments (Brown, Collins & Duguid, 1989). The authentic environment of field-ecology research was represented in my study by means of *field-complexity* that includes working under uncontrolled, and sometimes unexpected, natural conditions. This resulted in the challenging impact of the environmental conditions on the research sites as well as on the students themselves. Furthermore, working under uncontrolled environment demanded of the students to apply specific field tools, deal with the unexplained variance of the field and also manage their limited time of working in the field. These challenges strengthen Roth and Bowen (2001a, 2001b) description of field ecology practices as requiring physical, emotional and mental disciplines. Additionally, these challenges adequately express the key methodological elements of ecological natural experiments that prevent any manipulation over independent variables due to the confounding complexity of field conditions, which remain wholly uncontrolled (Diamond & Case, 1986; Holling, 1998). Other than working in an uncontrolled environment, another major challenge that added more weight to field-research complexity, originated from the setting of the field-based research. This setting involved students working mostly alone on a distant site which isolated them from authoritative guidance as well as challenges involving their interactions with their research assistants. This challenging characteristic of physical
isolation in field-ecology research was also mentioned by Roth & Bowen (2001b) who associated the lack of feedback as contributing to the students' insecurity about the quality of their work.

My research findings conclude that field-complexity was in fact the keystone element for students' challenges. Similarly, the students' knowledge, research skills and motivation (i.e. the learning components) that enabled them to cope with those challenges were all affected by the complexity of the field. Knowledge elements were represented as course-based declarative knowledge and field-experienced procedural knowledge. Field-based research skills were characterized as (metacognitive) coping strategies which the students used to bridge the dynamic tension between their idealized research protocols and the reality of the field. These strategies were termed 'protocol-dominated' [PD] (i.e. implementing only what is possible as defined in the research protocol), 'intermediate' [INT] (i.e. using the planned protocol with immediate flexible changes in the field) or 'field-dominated' [FD] (i.e. alternative planning for implementing the research based on the reality of field conditions). Another strategy which was solely mentioned by experts was termed PD2 and included making an educated decision to maintain the protocol. Last but not least, students' Motivation was represented by the factors that encouraged or discouraged their research and were specified by their intrinsic or extrinsic orientations.

As was seen, each of these learning components were essential on their own for becoming a field-ecology researcher. Nonetheless, comprehending their interactions allowed a fuller understanding of this learning process. These interactions were expressed when directly experiencing field-complexity reinforced students' motivation to acquire the knowledge needed in order to adopt the strategy that best solve the current challenge they faced and strengthen their development of research skills.

Based on this characterization of learning to conduct field-ecology research and in order to add a deeper perspective on the development of expertise in this specific domain, my study also provides a longitudinal comparison of how M.Sc. and Ph.D. students respectively view and respond to specific research challenges. My findings are similar to those presented previously by Feldman, Divoll and Rogan-Klyve (2009) of a transition in expertise from less independent M.Sc. students who lean heavily on both their advisor and their (advisor-designed) protocols to more
independent Ph.D. students who relate to their advisor as consultant / partner rather than one who dictates the research direction.

As this qualitative study focused on one research group, I cannot assert that M.Sc. students, in general receive a prepared protocol from their advisor, nor that all Ph.D. students independently design their own protocols. However, I do see a causal effect between the involvement of the students in the preparation of the research plan, which makes them better aware of the field complexity, and their ability to cope with research challenges by adapting their protocols to the changing conditions of the field.

Concerning specific challenges, the M.Sc. candidates were most affected by practical issues of methods and tools (chiefly in their 1st research year) and environmental factors (particularly in the 2nd research year) which weighed on them heavily, given that that they needed to finish their research in a rather short time period; in contrast, Ph.D. students forge their own direction and hence were concerned from the beginning of their research with core features of ecology as a science, such as unexplained variance and the conditions of their research plots.

Moreover, working with research assistants in the field, which produced challenges connected to training, deployment, and subjective sampling were reported only by the Ph.D. students, primary in their 2nd research year. This challenge was directly related to the increasing complexity of the Ph.D. students' research which in the 2nd year included multiple experiments and thus necessitated more assistants. Such a challenge is likely not exclusive to Ph.D. students in field-ecology research; in fact, any graduate student who use assistants for their (field) research should be aware of this specific challenge and how it is related to the complexity of their research environment.

The differences in how Ph.D. and M.Sc. students viewed the challenges were also reflected in their coping strategies. The M.Sc. students clearly leaned on their protocol which was reflected by their strong use of PD strategies throughout their research. However, their Ph.D. counterparts developed the experience and confidence to make both subtle and radical changes in their protocols, when needed. This does not mean that they must do this all the time; a further expertise level is intelligently choosing to preserve a protocol because the question being tested has important scientific value; this strategy which was termed PD2 was in fact mentioned only by the two Professors participating in this study.
My study's findings have various implications for the practice of science education. These implications include the training of field ecology graduate student as well as the preliminary undergraduate experiences and even K-12 inquiry-based ecology learning. I will describe each of these implications in the following:

5.1 Implications for graduate students in field-ecology

The lack of science education research on cognitive apprenticeships in complex field environments creates a gap in the ability to help graduate students develop field-research expertise. By exposing the challenges and their coping strategies this research helps to better prepare novice ecology students towards acquiring that expertise.

Similarly, an understanding of these issues will help ecology Professors to improve their ability in guiding their students. The importance of being aware of field complexity is a message that advisors must instill in their graduate students. Although even novice (M.Sc.) students are aware that it is impossible to control the research environment, they still found it hard to adjust their protocols to this reality, knowing what to modify and what to maintain. Moreover, advisors should improve their students' recognition of the dynamic tension existing between the research protocol and the reality of field conditions so that they are prepared to adapt their reasoning and actions accordingly. Knowing that there is a set of strategies available for problem solving can promote the students' ability to make the most educated decision possible when coping with their field-based research challenges.

Moreover, my subjects' intrinsic motivation of deep-set interests in their particular discipline improved their knowledge and research skills. Thus, advisors should be aware of such factors so that they can strategically use them to encourage their students when they are frustrated by field complexity. Concurrently, it permits advisors to better help their students adopt their coping strategies to the contingencies of their research problems.

My findings suggest that novices will implement their research protocols more effectively if their advisor, or even an experienced student, is present at the beginning of the research to scaffold the skills needed for coping with such complex, uncontrolled conditions. This can reduce the professional challenges of novice students who are forced to make independent decisions in the field away from
authoritative guidance. In fact, Yifat (the advisor) acknowledged the important role of an authoritative field voice after reviewing my conference paper concerning how students cope with field complexity (Leon-Beck & Dodick, 2011). While taking note of the “different strategies of beginning and more experienced students”, she also recognized that “beginners need more support in the field.”

This suggestion accords well with the cognitive apprenticeship model in which novices learn best by having an expert model the needed competencies to pursue a specific task. In turn, novices independently repeat the expert action while explicitly explaining the reasoning behind its implementation (Collins, Brown, & Holum, 1991; Collins, Brown, & Newman, 1989).

As suggested by Feldman, Divoll and Rogan-Klyve (2009) students who are members of loosely organized research groups (such as field-sciences) are less exposed to apprenticeship learning than tightly organized research groups (such as laboratory sciences) since they have less frequent contact with students in different levels of expertise which could mentor and guide them in their research (in addition to their professors). However, by understanding the importance of apprenticeship in the research group as a community of practice, the writers emphasized that even in loosely organized groups, professors need to recognize the important role that peer mentoring plays on students’ research and consider training students to improve the outcomes of these relationships.

Indeed, both advisors participating in this study (Yifat and Yonathan) mentioned in their interviews that it was important to pair a novice M.Sc. student with an experienced Ph.D. candidate for conducting fieldwork. This was not possible all the time, but they did pair students when they were working in the same area. In interviewing and observing the students I noted how cooperation between the two benefitted both students. The more experienced Ph.D. student could monitor the progress of the M.Sc. student. In turn, the Ph.D. student received valuable fieldwork assistance, while concurrently improving both his / her research knowledge and skills by helping to direct the research of another student; this forced him/her to reflect on different (and sometimes new) elements of field-research, as was expressed by Ayala (a Ph.D. student):

"When I talk to someone- I need to actually say things out load - and it defiantly improved my thinking process [...] especially when they (M.Sc.
student and two other research assistants) ask questions it made me think why am I doing what I am doing.” [Ayala, 2nd year Ph.D., interview]

Mentoring skills were also evident in my study when Ph.D. students trained and deployed their research assistants in the field. My findings disclose that the students mentoring skills were learned through doing and were partly based on their intuitive recognition of what they thought they needed most when they were novice researchers in the field.

Based on Feldman, Divoll and Rogan-Klyve (2009) findings about the importance of research group apprenticeship, another suggestion resulted from my study would be to improve the mentoring skills of students working with research assistants in field-based research. Thus advisors should prepare students to the specific challenges involved when working with field-research assistants and even model the mentoring skills required to cope with such challenges in the field.

Another strategy for achieving cognitive apprenticeship in loosely-organized groups (such as field-ecology teams) is by participating in regular research group meetings, journal clubs and even social functions of the scientific domain (Feldman, Divoll & Rogan-Klyve, 2013). Indeed, in the group meetings that I observed, the students discussed important professional articles, or presented their research proposal or results which contributed to both their declarative and procedural knowledge in the discipline of field-ecology. However, I suggest that by adding a further, metacognitive component in which the students specifically discuss the particular challenges as well as the coping strategies they exploit in the field, they can learn from their own actions and from other group members and thus increase their field-research skills and consequently their development of expertise.

Dunbar’s (2001) cognitive studies support this contention. His in vivo investigation of molecular biologists documented how group meetings, in which the scientists must defend their actions and results, was where much of the innovation in the lab typically occurred, and not while poring over their microscopes. Dunbar (1999, 2000) suggests that it is the distributed nature of the group’s problem solving that leads to conceptual change and thus spurs such innovation. In fact, he found that individual scientists were sometimes unaware of the fact that an insight they achieved occurred due to their participation in meetings and instead believed that it occurred during individual bench work.
Furthermore, based on the students’ positive responses to the assessment reports and due to their field isolation, the use of such reports can be considered to be a critical tool for improving student performance. For the students, such reports require that they reflect on their work (and by doing so, be better aware of the challenges and their responses) while subsequently they get feedback from their advisor. For the advisors, especially for those who guide their student from a distance (such as in field-ecology research) the assessments provide them with greater insight into the specific challenges confronting their students and so permit them to provide more productive guidance. In addition, the assessments produce an ongoing dialog between students and advisors which promotes the students’ "sense of belonging", which was illustrated by Curtin, Stewart and Ostrove (2013) as an important (affective) component of an advisor’s responsibilities.

As noted in the introduction, recent studies confirm that an advisor’s support plays a key role in the experiences of doctoral students (Curtin et al., 2013; Heath, 2002). In fact, Fletcher, Gies and Hodge (2011) specifically identified four concerns that doctoral students had about their relationships with their advisors: (a) a lack of advising, (b) a lack of feedback, (c) a lack of mentorship, and (d) a disconnect between the advisor and advisee’s research interests. Certainly the first three concerns are largely connected with the advisors busy time schedule. The assessment tool addresses these concerns as it was designed to be a concise, systematic journal of a student’s progress, which can be quickly completed and evaluated, respectively by students and advisors (See Appendix 3).

Heath (2002) has shown that there was a positive significant correlation between the frequency of students' meetings with their advisors and their likelihood of finishing their Ph.D. It is often hard for Professors with their busy schedules to meet with their graduate students, even when they are working in a nearby laboratory (as mentioned by Yonathan, an experienced advisor); this could even be more crucial when their students are conducting field work. The assessment report can act as bridge which compensates for the fact that student and advisor are (physically) distant during their field-based research and can therefore not meet for direct consultation. This is especially critical for the M.Sc. students, who had much more difficulty in making independent decisions in the field, as well as needing more consultations with their advisor in comparison to the Ph.D. students.
In her discussion about learning in academic environments, Alexander (2003, p.14) argues that 'the journey towards expertise is unceasing. Even those who have attained the knowledge, strategic abilities, and interests indicative of expertise cannot sit idly by as the domain shifts under their feet. We, thus, do a disservice to learners by conveying the idea that learning some set body of facts or procedures is the educational end'. My study's findings concur with Alexander and would add that this is even more crucial when a graduate student makes what Lovitts (2005) called the "critical transition" from course-taker to independent researcher. Indeed, in the case of graduate students conducting field research (specifically) this message of "domain shifts" must be constantly reinforced because every time they start a new research venture they cannot guarantee that their present educational background will help them to solve the complex challenges presented by a new field site; thus even when developing a greater level of expert competencies, they must constantly renew their learning experiences to adapt to the new challenges that confront them.

Future research should compare systematically lab vs. field-based sciences to provide a greater understanding of graduate student learning. More than ever, the 21st century is being shaped by science and technology, so graduate student learning is becoming a recurring and pressing topic. Indeed, in the United States the professional (Isaak & Hubert, 1999) and popular media (Broad, 2004) has highlighted the difficulties in retaining graduate students until they complete their degrees. This problem is so serious that it has inspired several well-funded projects such as the Carnegie Initiative on the Doctorate (Golde, 2003), whose goal was to develop a framework for improving graduate training of science students. In the spirit of that report, my in-depth qualitative study is a small step towards developing the means to both monitor and improve graduate science education. Potentially, this study can be used as a precursor study for an extensive quantitative survey study. The identified series of challenges and their respondent learning components can serve as a necessary conceptual framework to perform a large-scale quantitative study of M.Sc. and Ph.D. students in field-ecology (and even possibly other field sciences).

5.2 Implications for undergraduate experiences

As mentioned above, understanding the learning environment of field-ecology research can improve how novice graduate students acquire expertise. I suggest that to
really understand the field environment field-research training should begin in undergraduate scientific learning. Indeed, three of my subjects (Tidhar, Uri and Ayala) mentioned that it would have been very useful if they had encountered a preliminary course that based on the results of research like mine, would have forewarned them about what to expect from field-ecology research.

In fact my interviews showed that some of the students had the option of taking field-based ecology courses as part of their undergraduate degrees. Such courses focus, among other things, on exposing students to the procedural knowledge or methods needed to pursue field research. This is critical in that I have seen that applying field methods and tools was one of the most pressing challenges of graduate ecology research. Still, as Yonathan, my more experienced advisor argued in a 3rd year interview such courses are often limited because the established, “classic methods” which are taught have no connection to the “complex research” that the student will be pursuing as they require “ad-hoc” solutions. Thus, not only should such courses be a mandatory (and not selective, as mentioned by the students) but they also must be constantly updated so that students are encouraged to design their own protocols while moving beyond the standardized methods.

Therefore, I suggest that undergraduate ecology courses should be more strongly situated within natural field environments. This can provide the students with the perceptive of field-ecology complexity as well as the opportunity to develop more quickly the knowledge needed to cope with ecological research challenges. In such field research courses they would be explicitly taught to be cognizant of the constant tension existing between the idealized research protocols and the reality of the field. Thus, they would be better prepared to cope independently with field work complexity by developing more quickly the research skills needed at the beginning of their graduate careers. This suggestion fits well with the situated learning movement which argues that deep learning occurs when students activate specific tools while pursuing activities in authentic environments (Brown, Collins & Duguid, 1989; Driscoll, 2005).

However, more than just knowledge factors into developing research skills; motivation is also intrinsic. my results show that complexity imposes itself the minute inexperienced students venture into the field; this can be potentially frustrating which initially can negatively impact on (some) students’ motivation, which then affects how they execute their research. However, when the students knows better what to
expect, and when accumulation field experience, that enables them to acquire the knowledge and skills needed to overcome the field’s complexity, students’ motivation improves. This again emphasizes the idea that undergraduate students should be taking research-based courses that expose them to both frustrating and exciting experiences of fieldwork.

The suggestion of participating in undergraduate courses resonates with the 1996 NSF grant (96-139): “Shaping the Future of Undergraduate Education” which called for undergraduate science education being reformed to emphasize inquiry. There are many definitions of this term, but for my purpose, learning by inquiry incorporates the type of investigations conducted in authentic science environments. The understanding is that through exposure to such environments, students will not only learn more content, but will also develop the necessary critical thinking skills to pursue independent work in science (Dodick & Argamon, 2006).

This idea of participating in preliminary field courses also fits well with Schoenfeld (1985) who notes that (metacognitive) strategies must be acquired and practiced in relevant situations that allow students to witness their inherent value. Moreover, as Alexander (2003a) suggests, students must be encouraged to modify strategies in ways that fit the problem at hand. Authentic field-based courses provide that opportunity for novice ecologists.

Finally, participating in undergraduate courses that expose students to authentic research environments is also one of the recommendations of the Bio2010 report (NRC, 2003) published by the U.S.-based National Research Council, which calls for incorporating independent research experiences in an undergraduates' education in order to fully prepare them for graduate study as well as enabling them to experience the excitement of creative biological inquiry. My findings support this recommendation and add that engaging in research courses could be even more critical for students working in field sciences, than their lab counterparts, as they work mostly alone, isolated from authoritative support and are plagued by many more uncontrolled and thus complex challenges.

5.3 implications for K-12 inquiry-based ecology learning

The results of my study also have collaterally implications for less experienced students who are learning inquiry-based units in ecology, specifically and field
sciences in general. This is based on the argument that inquiry itself models students’ learning activities on (expert) scientists’ methods of discovery (NRC, 1996, 2000; AAAS, 1990, 1993). Thus, it is not unreasonable to think that if a particular challenge confronts graduate students, who are transitioning towards scientific expertise; it is likely that it would affect their less experienced counterparts, both at the undergraduate as well as the high and middle school level. Sternberg (2003) has similarly argued that experts can serve as models of good practice for less experienced students.

Finally, Feldman, Divoll and Rogan-Klyve, (2013, p.219) added that "if we want teachers to be able to teach others how to do research, they need to know how to do it themselves". Simply put, studies such as mine provide another tool for modeling the practices of field-based inquiry learning.

In Israel these suggestions have practical significance as more than 50% of all Biology high school students currently pursue a final year inquiry project entitled, *Bio-Investigate*. The Ministry of Education has made this project mandatory for all high school biology students – approximately 15,000 in total-starting in 2014 (Pers. comm. with Ilana Adar, Head of the Israeli Center for (High School) Biology Teachers). Since some of these projects take place under complex field conditions these students are also confronted by some of the same challenges confronted by our subjects. Such challenges certainly include the uncertain environmental conditions associated with their research plots and the weather. So too, implementing research methods is also problematic, especially for high school students who have had almost no opportunity to master these field research techniques. This of course can affect how they manage their time and how they deal to some extent with experimental variance. Regarding this last element, Kuhn and her colleagues (Kuhn, Black, Keselman, & Kaplan, 2000; Kuhn & Dean, 2005) have shown the difficulties that middle and high school students have in understanding the effect of independent variables on dependent variables while doing experiments under controlled conditions in school laboratories. Statistics for the nationwide matriculation exams for Israeli high school biology students corroborate this fact (National Center for Teachers of Biology, 2006). I believe that such difficulties would only be compounded while studying science under the complex, natural conditions of the field.

The sciences that students encounter prior to university are weighted towards the experimental and lab-based. Such sciences certainly have their own unique
complexity, and importance for developing scientific literacy. However, the development of an integrated inquiry-based science curriculum will also require understanding about how field-based scientists do their research (Dodick, Argamon, and Chase, 2009). This will enable educators to broaden the science curriculum to incorporate to greater degree field sciences that will expand students' understanding of different modes of scientific reasoning, as well as provide more opportunities for students to pursue further science education.
6. Publications resulting from this thesis research


7. References


8. Appendixes

Appendix 1: introductory interview protocol for the graduate students

This represents the protocol of the first interview with the graduate students of the sampled group. Note that as my research progressed, in the following interviews, the protocols changed according to events in the students' research and in order to clarify findings from the field observations, field-assessment reports and questionnaires.

1. Tell me a bit about yourself (personal and professional background); what got you interested in this field? (Specifically, how and when did you learn about ecology? In High-school? In University?)

2. What is the research question that you are pursuing? Where did you get the idea for this research? (Literature? Advisor? Other?)

3. How did you learn the skills that you need to pursue your research?

4. Can you please describe a typical day for you while working on your research?

5. What do you do when you are in the field? What do you do in the laboratory? How do you connect between the work that you do in the field and the work that you do in the laboratory? Similarities? Differences?

6. What is difficult about working independently in the field and lab? What are your difficulties when working with your advisor in the field and the lab?

7. How do you know what to look for and which data to collect when you are in the field? How do you know what types of questions to ask?

8. Where do you prefer working? In the field or the laboratory? Why?

9. What types of technology do you use in the field? What are its limitations and its strengths? What about in the laboratory? What are its limitations and strengths?

10. How does interacting with other lab members (students or technicians) help with your research progress?

11. How does your advisor help with your research progress? Do you think she has an influence on your research stance? If so, in what way?

12. How do the formally research group meetings help with your research progress? Are there informally meetings between the members of the group? If so, do you think they help you with your research?

13. Do you think that there is a fundamental difference between sciences that are (largely) pursued in the field (such as ecology) and sciences that are pursued in the lab (such as molecular biology or physical chemistry)? If so, how do they differ?

14. What are your plans for the future (when you will finish this research)? Are you thinking of staying in the field of ecology?
Appendix 2: introductory interview protocol for Professor-advisors in field-ecology research

This represents the protocol of the first interview with Yifat, the advisor of the sampled group, and Yonathan, an additional experienced advisor in field-ecology. Note that as my research progressed, in the following interviews with Yifat, the protocols changed according to the progress of the students in their research.

**Background**

1. Tell me about your experience with science when you were in K-12 school. What stands out as a particularly positive experience? What stands out as negative? Where did you go to college and what was your undergraduate major? How did you become interested in studying science?

2. Where did you do your graduate work? What were your dissertation topics? What got you interested in these topics? Do your graduate researches relate to your current study, if so, in what way?

3. Why did you decide to become a scientist in academia? What are some of the things that you like about being a scientist at a university? What are some that you dislike?

4. What was your learning experience like in graduate school? How did your advisor in graduate school affect what you learned? How did it affect your career path?

**Current Research**

5. What is the focus of your current research? What do you expect it to add to your field?

6. Where do you think the research will lead and what plans do you have to continue his line of research in the future?

7. When this particular research project is completed, what will determine whether you consider it successful or not?

8. Please describe your research group. Who are the members of it and what roles do they play? What are you and your students do as part of this research project (both fieldwork and lab work)?

9. How is the fieldwork and lab work connected to each other and to the overall research project? What role does each play in your research? Are there any differences in the roles that fieldwork and laboratory work play in your research?

10. How do you decide on the types of methods that you use and what data you collect in the field and in the lab?

11. What types of technology do you use in the field? What are its limitations and its strengths? What about in the laboratory? What are its limitations and strengths?

12. What goals do you have for your students who are working with you on this research project? What are your expectations for their work? What do you
expect them to do and to accomplish? What are some of the things that you do to help your students meet your goals for them?

13. Are there any differences between the ways in which you advise your students in the field and in the laboratory? If so, what are they?

14. What are some of the difficulties that students have when working under your guidance in the field and the lab? What are some of the difficulties that students have when working independently in the field and the lab?

15. What is the source of your students' research questions? Do they change as they do their research? What are some of the factors that cause them to change their questions?

The research group

16. Please describe the way in which your research group works (interactions among people, research group meetings, etc). Are these interactions typical for a research group in ecology? How does this compare with other research groups?

17. What is the purpose and what do you do in your formally research group meetings? Are there informally meetings between the members of the group? If so, what do you think is accomplished in these meetings?

18. How is your groups’ research progressing? As your expectations? How do you measure the success of your research group?

Fieldwork vs. Lab work

19. Do you think that there is a fundamental difference between sciences that are (largely) pursued in the field (such as ecology) and sciences that are pursued in the lab (such as molecular biology or physical chemistry)? If so, how do they differ?

20. Where do you prefer working? In the field or the laboratory? Why?
Appendix 3: Example of graduate student (ecological) field notes

This represents an example of Uri's field notes which demonstrates his handmade map for one of his field-research plots. Uri's M.Sc. research is done on the influence of post-fire salvage logging on soil-dwelling arthropods. Uri made this map while implementing his first sampling season in the field. According to his descriptions (in a sequential interview) using this map made it easier for him to be familiar with his plots which were scattered all over the forest. In addition these maps also helped him to remember the locations of his traps in each of his plots.

As this field notes were written in Hebrew, I have added translation to each of his marks, with an added description from Uri's interview.

16/109A represents the plot number.
Also noted is the type of this experimental plot which is "burnt logged"

The direction of the arrow represents northwardly

Each of these circles (a-d) represents an area in the plot where he placed four traps (represented by small dots)

This drawing represents a logged laid bole in that area, which assists Uri to better locate the traps areas

This drawing represents a logged bole which was tape-marked by Uri in that area, which assists him to better locate the traps areas
Appendix 3: Field assessment report

This represents the text of the field assessment report that the subjects completed while in the field during their first two research years. In the real report room was left for their responses.

Name:  

Date:  

Field Location:

Please fill out this report at the end of each field day.

• What was my research goal for today, and how much of it did I accomplish?
• The methods/tools that I used today:
• The Problems that I dealt with today:
• I deal with those problems in the following ways: (alone, with the help of my advisor/another student, paper I read, method that I learned in a course)
• Questions that arose from today’s field session:
• Ideas for improving research efficiency:

Thank you for participating!
Appendix 4: Questionnaire concerning expertise development in field-ecology research

This represents the text of an open questionnaire that the subjects completed on the 2nd year of my research (March, 2010). This questionnaire was based on essential categories emerging from the interviews, as well as the filmed protocols, which were connected to the development of research expertise.

Note that the original language of this questionnaire was Hebrew. Moreover, in the original questionnaire, space was left for subjects' responses.

**Questionnaire on the development of expertise in field-ecology research**

The purpose of this questionnaire is to validate the analysis of my research which deals with the characteristics of field-ecology expertise. I ask you fill out this questionnaire on your own, without any consultation. Your personal opinion is important to me and for my research. If any question is not understandable, please contact me so that I can clarify it for you. Thank you.

- How would you define an expert in field-ecology research? (Major criteria)
- What do you think you lack now in order to be an expert in field-ecology research?
- Do you think the level of your expertise improved during your research? If so, please give an example; if not – please explain why.
- Try to recall what particularly contribute to this improvement? How is your expertise level reflected in your research?
- What is the source of motivation for your research? Has this source changed throughout your research?
- Do you think your experience or the previous knowledge you had at the beginning of your research influenced your ability to progress in your research as well your expertise development? Please explain.
- "The inability to anticipate the various elements of the field and their change over time creates many challenges for field research". What do you think about this statement? Did you experience these types of challenges in your research? Do you think that coping with these kinds of challenges contributes to you becoming a more professional researcher? When answering please provide examples.
Field research challenges can be categorized into three different types: 1. **Implementation** challenges (which includes technical challenges, challenges connected to planning an experiment, and challenges in setting up the experiment in the field) 2. Challenges involved with the **nature** of the research (if and how the phenomenon can be tested) and 3. **Emotional** challenges. Please present examples for each of these challenges from your research:

1. **Implementation challenges**
   - 1a. Technical challenges (concerning field methods and tools)
   - 1b. Challenges in planning the field experiment (before arriving to the field)
   - 1c. Challenges in setting up and conducting the experiment in the field (with regards to the complexity of working in a natural environment)

2. **Nature of research challenges** (if and how the phenomenon can be tested)

3. **Emotional challenges**

4. **Additional challenges that did not appear amongst these categories**
   - Coping with research challenges can be expressed in several ways: accepting the problem (there is no solution), compromising (there is a solution, but it is not ideal) or finding a proper solution (alone, or with the help of others).

   Please add examples from your coping approaches when facing field-research challenges:
   - 1. Accepting the problem (there is no solution)
   - 2. Compromising (there is a solution, but it is not ideal)
   - 3. Finding a proper solution
     - 3a. Finding a proper solution **alone**
     - 3b. Finding a proper solution **with the help of others** (for example: advisor or other experts; literature; group members; department members, research assistants).
   - 4. Another coping approach that did not appear amongst these categories

5. **Please offer your opinion to the following statements. Note all refer to field-ecology research expertise and not to expertise in general.** (Please avoid changing your answers to the previous part of the questionnaire after reading these statements. Your intuitive and personal answers are the most relevant ones for my research).
1. A field-ecology research expert has extensive **knowledge** in ecology and in research methodology.

2. A field-ecology research expert knows how to distinguish between significant and insignificant elements in the research, knows what can be applicable for research and therefore knows how to ask the right questions.

3. A field-ecology research expert knows how to solve problems effectively.

4. A field-ecology research expert **must** have scientific competencies (the ability to plan experiments, the ability to create a hypothesis, the ability to analyze statistical results, the ability to state (definitive) conclusions).

5. A field-ecology research expert is a field person by definition. He/she lives, feels and understand the field he/she is investigating.

   **Thank you for your cooperation.**
רכישת מיומנויות חקר והאיפורים בחוליפי החקר והتعاون בחטבור-שדה של סטודנטים באקולוגיה

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דר"ר גבי אדוים.
תקציר

מחקרים קודמים על תהליך הלמידה של סטודנטים במדעי הטבע התמקדו בעיקר במדעים הניסוייים המתקיימים בתנאי מעבדה; לנגדיהם, מטרת מחקר זה היא להאריך את סיבוב הלמידה של סטודנטים במדעים השדהיים, ובראשם מחקר לאכולוגיה. מחקר זה יאני את סביבת הלמידה לתהליך התמחות הייחודי של סטודנטים המבצעים מחקרים שדהיים, המשלב את התמחותם במדעי השדה בין השאר, בעיות במטורפטים במדעי השדה, ובעיות של החברת הסטודנטים עם הסטודנטים Janeiro והם מנהלים מחקרים אחרים. מחקר זה התמקד בכל הגיוון של המחקרים השדהיים במדעי השדה בה��ית תהליך الحوثים במדעי השדה. מחקרים אחרים, מתוכננים ליישם מחקרים שנעשו על ידי המחקרים אחרים, משנים את התהליך של המחקרים אחרים, והם יקרים יותר משל מחקרי אחרים שHarness ולהם תוצאות של מחקרים אחרים, וחותם על תוצאות מחקרים אחרים שHarness.

שלימוי מחקרים נוספים לשנת לאסכולה של מחקרים אחרים, ונותנים מחקרי אחרים של מחקרים אחרים שהמשיכו במחקר של מחקרים אחרים שהמשיכו במחקר של מחקרי אחרים.

ניתוח הנתונים התבצע כניתוח איכותני-Constructed נושאי על ידי טריאנגולציה של מקורות המידע שונים. מחקרי אחרים של מחקרי אחרים שהמשיכו במחקר של מחקרי אחרים שהמשיכו במחקר של מחקרי אחרים משנים את התהליך של המחקרים אחרים, ומחקרי אחרים של מחקרי אחרים שהמשיכו במחקר של מחקרי אחרים שהמשיכו במחקר של מחקרי אחרים משנים את התהליך של מחקרי אחרים, ומחקרי אחרים של מחקרי אחרים שהמשיכו במחקר של מחקרי אחרים משנים את התהליך של מחקרי אחרים, ומחקרי אחרים של מחקרי אחרים שהמשיכו במחקר של מחקרי אחרים משנים את התהליך של מחקרי אחרים, ומחקרי אחרים של מחקרי אחרים שהמשיכו במחקר של מחקרי אחרים משנים את התהליך של מחקרי אחרים, ומחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במחקרי אחרים של מחקרי אחרים שהמשיכו במח DispatchQueue המחקרי, דו-אוזית נ.genius למחקרי אחרים.
The research field challenges highlight a significant gap between the original research plan and the reality students encountered in the field. Therefore, in our studies, we examined the ways students responded according to the extent of adherence to the original research plan during field experience in varying conditions.

Strategies of response included adherence to the original plan, even when it did not suit the conditions they encountered. Meanwhile, the doctoral students showed much greater flexibility in the field and acted primarily by implementing significant changes in the initial research plan.

However, it is not possible to conclude from this that higher expertise always justifies changing research plans. In fact, another strategy, only noted by the supervisor, expressed in the deliberate choice to adhere to the original research plan in cases where the question under study has scientific value.

This research has practical implications for the guidance and training of students in the field. Thanks to increased awareness of the challenges and strategies of response unique to research in the field.

It is fitting, therefore, for supervisors to emphasize the possible gap between the research plan and field reality so students can deal with the various challenges while making informed decisions as well as appropriate advice in various experts.

In addition, based on the cognitive education model, research findings suggest that tyrants can implement their research more effectively when they are either experts or experienced students who accompany the initial work in the field to present the skills and knowledge required to cope with the complex and unpredictable conditions of the field.

In this regard, communication between students and supervisors can be expressed in discussions of the challenges they encounter in the field and the strategies they have implemented. Such a discussion can take place within group meetings or seminars and can be supplemented in writing by 'field sheets' as was done in our studies.

Finally, in addition to the practical implications for the guidance and training of students in advanced degrees, this research also has implications for other levels of scientific education. In particular, practical scientific experience of students in natural sciences at the Bachelor's level and in schools could increase students' awareness of research in the field and enable them to better understand the complexity of field research as well as acquire the unique research skills required to deal with research challenges in this area.