Turning students into Industry 4.0 entrepreneurs: design and evaluation of a tailored study program

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Abstract
Startups in the field of Industry 4.0 could be a huge driver of innovation for many industry sectors such as manufacturing. However, there is a lack of education programs to ensure a sufficient number of well-trained founders and thus a supply of such startups. Therefore, this study presents the design, implementation, and evaluation of a university course tailored to the characteristics of Industry 4.0 entrepreneurship. Educational design-based research was applied with a focus on content and teaching concept. The study program was first implemented in 2021 at a German university of applied sciences with 25 students, of which 22 participated in the evaluation. The evaluation of the study program was conducted with a pretest–posttest-design targeting three areas: (1) knowledge about the application domain, (2) entrepreneurial intention and (3) psychological characteristics. The entrepreneurial intention was measured based on the theory of planned behavior. For measuring psychological characteristics, personality traits associated with entrepreneurship were used. Considering the study context and the limited external validity of the study, the following can be identified in particular: The results show that a university course can improve participants’ knowledge of this particular area. In addition, perceived behavioral control of starting an Industry 4.0 startup was enhanced. However, the results showed no significant effects on psychological characteristics.

Keywords Entrepreneurship education · Industry 4.0 · Industry 4.0 startups · Industrial internet of things (IIoT) · Theory of planned behavior · Educational design-based research

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Introduction

There is a growing number of entrepreneurship education programs designed to enable entrepreneurs and innovators to turn ideas into successful business models (Kuratko, 2005). These programs focus on imparting the generic principles of identifying opportunities and acting on them, envisioning the future, developing entrepreneurial traits and running a new business (Mkwanazi & Mbohwa, 2018). They are either tailored to the specific needs of a certain sector such as social entrepreneurship (Wiepcke, 2019) or sports entrepreneurship (Ansari et al., 2020) or teach entrepreneurship competencies without further specialization. Even though the global industrial landscape has changed tremendously and Industry 4.0 (I4) plays an important role in this change (Pereira & Romero, 2017), scientific foundation, education and supportive services for startups in this area seem to be largely lacking. Previous studies have shown that startups in the field of I4 have specifics that potentially have an impact on a broad spectrum of the entrepreneurial process and accordingly, the education and support of entrepreneurs in this field must be adapted. However, entrepreneurship education is not addressing this topic sufficiently yet (Wahl & Münch, 2021). While there is basic research as well as dedicated teaching and training opportunities for other sub-disciplines (see Ansari et al., 2020; Nambisan, 2017 or Kollmann et al., 2022), the field of I4 entrepreneurship remains largely untouched. The question therefore is: How can the special characteristics of the field I4 be integrated into training and what effects will this have? An important research gap can be identified here: There is a lack of scientific studies on training for entrepreneurs or future entrepreneurs in the field of I4. This relates especially to the relevant characteristics of this domain, the design of corresponding programs and the study of the effects of such programs.

The circumstance that the described areas are not addressed sufficiently yet is a missed opportunity and a threat at the same time. Integrating I4 into existing entrepreneurship education programs can increase the competency of undergraduates for their future jobs and by that also increase their employability (Nhleko et al., 2022). In addition, I4 startups are a needed resource for production and manufacturing dependent countries not only as a source of job creation and taxes (Vodă & Nelu, 2019) but also as a driving force for innovation, inspiration and efficiency (Spender et al., 2017). In Germany for instance, the automotive and manufacturing industries are the two sectors with the highest turnover (Statista, 2020). These two industries alone are responsible for around 20% of Germany’s gross domestic product (GDP). These industries could benefit tremendously from utilizing I4 solutions for process optimization, cost reduction, quality improvement or satisfying customer needs. This seems to be the explanation why in 2021, 83% of companies with more than 100 employees either use or plan to implement I4 solutions (Statista, 2022). Open innovation by cooperating with I4 startups can be an efficient approach to implement I4 technologies in existing companies without developing the technologies themselves (Spender et al., 2017). The advantages of open innovation are reduced development times, development costs as well as other desirable effects such as cultural mindset change (Kanbach & Stubner, 2016).
Open innovation approaches could benefit from a sufficient supply of I4 solutions and products developed and marketed by startups. These startups need to be able to fulfill customer demands and develop products or solutions that have an impact on the value chain of their customers. Capable entrepreneurs for the specific field of I4 are a necessity for successful startups. Entrepreneurship education has the goal to improve the skills of entrepreneurs and thus to create “better” startups (Rasmussen & Sørheim, 2006). However, it is necessary to prepare aspiring entrepreneurs not only for the specifics of startups but for the very specific field of entrepreneurship in the domain of I4 (Mkwanazi & Mbohwa, 2018). Entrepreneurship education programs contextualized in non-business disciplines have been discussed in the literature and some researchers have even addressed this topic in detail (see Ansari et al., 2020; Brizek & Poorani, 2006; Roberts, 2012). However, literature including examples of effective delivery of entrepreneurship education in specific disciplines still seems to be limited (Ansari et al., 2020).

The following research question (RQ) was formulated to address the described research gap as well as the lack of literature and specific educational programs in I4 entrepreneurship:

**RQ: What are the essential characteristics and constraints of entrepreneurship education in I4?**

This research question was further broken down into sub-questions:

- **RQ1:** What are the requirements for a study program in the field of I4 entrepreneurship?
- **RQ2:** How can this study program be designed to meet the defined requirements?
- **RQ3:** How can the designed study program be evaluated?
- **RQ4:** To what extent does the designed study program meet the requirements?

To answer the research questions, a university course tailored to entrepreneurship in I4 was designed, initially conducted, and evaluated. Educational design-based research (EDBR) was used as a guideline for this process. Based on a literature review and field-based investigation, the study program was designed with a focus on design elements such as content, teaching concept and project-based learning. In 2021, it was initially conducted at a German university of applied sciences with 25 students. The evaluation was conducted with a pretest–posttest-design and evaluated based on three criteria: (1) Knowledge, (2) entrepreneurial intention, (3) psychological characteristics linked to entrepreneurship.

The article is structured as follows: Chapter two describes the research methods used and their rationale. Chapter three describes the phase of analysis and exploration which is the basis of the design of the intervention that will be presented in chapter four. In chapter five the conduction and evaluation approach will be explained. Also, a reflection of the conduction according to the scientific framework is included here. The results of the evaluation will be described in chapter six and summarized and discussed in chapter seven. The limitations of the presented study
will be laid out in chapter eight together with future research avenues. Finally, chapter nine summarizes the article.

**Research methods**

As a framework for the conducted study, the scientific approach of EDBR was used. This research approach is defined as an “iterative development of solutions to practical and complex educational problems” (Mckenney & Reeves, 2019, p. 6). The goal of this approach is to gain usable knowledge for educational research while using an iterative approach. By doing so, EDBR offers a framework that enables a systematic improvement process and can therefore be applied to design and improve the study program for entrepreneurship education in I4.

EDBR specifies a set of core processes to enable practical development of appropriate teaching concepts. The overall framework consists of the following steps: (1) Analysis and exploration, (2) design and construction, (3) evaluation and reflection and (4) implementation and spread. In the study presented in this article, the first three of these core processes were gone through in order to develop an appropriate teaching approach. The fourth step facilitates the implementation and spread of the design and is not a part of the study at hand. It should be noted that the methods presented in EBDR are only a selection of potentially usable methods. The choice of tools varies and should be decided on the basis of the existing framework conditions. Following this, relevant methods were selected to best address the problem presented (Mckenney & Reeves, 2019). In the following section, applying the EDBR approach on I4 entrepreneurship is described:

**Analysis and exploration**

The fundamental goal in this phase is to gain a better understanding of the problem. According to Mckenney and Reeves (2019), three approaches are the biggest drivers of the analysis phase: Initial orientation, literature review, and field-based investigation. The initial orientation phase is primarily focusing on narrowing down the problem, context, and stakeholders. This was done through unstructured conversations and brainstorming with faculty and field experts. This is followed by a literature review aiming at a better understanding of the problem, giving ideas for structuring data and providing a framework for analyzing data. In order to cover the interface between entrepreneurship and I4, the literature review of this study focuses on the areas relevant to the design of a course. Based on the initial orientation and the literature review, the field-based investigation serves to define the problem and analyzes the context and needs. To cover this phase, an interview study was carried out beforehand, which highlighted the special characteristics in the field of I4 entrepreneurship and also queries initial approaches to the field of entrepreneurship.
education in this phase. As part of the interview study, 14 experts from the field of I4 entrepreneurship were interviewed. The results were analyzed qualitatively and discussed on a scientific conference (Wahl & Münch, 2021).

**Design and construction**

Based on the analysis, the next phase, namely the design and construction phase was carried out. In this phase, the findings of the analysis were transferred into a working design. Of particular importance for the present work is the mapping of the solutions through a morphological chart. EDBR makes a distinction between design requirements and design propositions. Design requirements are closely related to the long-term goals of the study program while propositions represent more concrete ways to achieve them. Based on these requirements and propositions a study program was constructed.

**Evaluation and reflection**

The constructed study program was conducted for the first time under real conditions. The study program was carried out in exactly the same environment in which it will also take place in the future and is intended to have an impact. Thus, the participants in the study program are automatically also the basic population of the students participating in the program. This also made a first evaluation of the study program possible. The participants were informed that the study program will be evaluated for scientific purposes and that the participation is voluntary. The evaluation was planned based on the requirements and propositions of the study program. The aim was to measure whether the requirements were met. For this purpose, a quasi-experimental design with a pretest–posttest-design was used. Since the students participated voluntarily it was not possible to assign the units randomly to the experimental treatment (Sreejesh et al., 2014). Therefore, an experimental design including a control group could not be applied. An evaluation questionnaire was filled out by the students at the beginning of the block week, before the study program started. The questionnaire was filled out again after the completion of the study program, namely during the week of the final presentation. Since completion of the evaluation was voluntary and could not be traced due to anonymization, not all of the 25 students but only 22 \((n = 22)\) of the participants fully participated in both assessments. This was mainly due to time constraints of the students. The questions in the evaluation form were divided into three areas: (1) Knowledge, (2) entrepreneurial intention and (3) psychological characteristics linked to entrepreneurship.

In addition to the quantitative evaluation, the reflection described in EDBR was also considered. This was primarily based on observations by the course instructor as well as individual feedback from the participants. The findings of the initial implementation will be incorporated into the design of the study program so that it can be continuously improved over the next few years.
Implementation and spread

There is also a fourth main phase which is implementation and spread. As the other phases, implementation and spread consists of sub-phases or processes. Since the goal of this study was to develop a study program and to initially conduct and evaluate it, this phase was not yet completed.

Analysis and exploration

The introduced methodological approach was applied starting with the phase of analysis and exploration. This phase primarily serves to better understand and classify the problem. Concrete outcomes of this phase are problem definition, long-range goal, partial design requirements and initial design propositions. In the phase of initial orientation, a basic understanding of the problem is to be created. To this end, an unstructured overview of existing offerings within and outside of a university context.

Literature review

The phase of analysis and exploration was started with a comprehensive literature review. To be able to answer the research questions and to transfer them into a suitable study program, the literature review focuses on the areas of entrepreneurship education, I4 education, I4 entrepreneurship education, the emergence of entrepreneurial action and psychological characteristics linked to entrepreneurship. The background to this is that the study program is intended to cover the specific interface of I4 entrepreneurship education, but in the absence of sufficient literature it must also make use of the two overarching areas of entrepreneurship and I4 per se.

Entrepreneurial skills and entrepreneurship education

The foundation for the design of the study program is provided by the literature in entrepreneurship education. Rasmussen and Sørheim (2006) state that the goal of entrepreneurship education is to train graduates to become future entrepreneurs or to improve the skills of existing entrepreneurs. Kuckertz (2013) extends the understanding of entrepreneurship education and mentions that the two main goals of entrepreneurship education are to increase the level of entrepreneurial competence and to have a positive impact towards entrepreneurial behaviors. He even calls the latter the “real challenge” in entrepreneurship education. In addition to these two goals, Kuckertz (2021) argues in an essay for the integration of a third mission into entrepreneurship education: character development. He urges entrepreneurship educators to continually reflect on whether this goal is being achieved. To achieve this, character development is set as a desired goal. Since
this mission has a strong linkage to psychological characteristics linked to entrepreneurship, this has to be considered.

Summarizing these findings, the long-range goal was set as the development and implementation of a study program that is able to train graduates to become future entrepreneurs or to improve the skills of existing entrepreneurs in the field of I4. Additionally, the study program shall have a positive impact on the entrepreneurial behavior of the participants and develop the entrepreneurial characteristics of the participants.

To address this broad goal, successful ways of teaching entrepreneurship were analyzed. Sirelkhatim et al. (2015) conducted a systematic literature review of curricula contents and teaching methods for entrepreneurship education. Their work gives a first overview and broad orientation on the status quo of entrepreneurship education. They conclude that there are three generic themes of entrepreneurship education which are:

1. Teaching about entrepreneurship
   Typical characteristics: Teacher-centered, focus on lectures, guest speakers and case studies, theoretical knowledge.
   Typical contents: Entrepreneurial traits, personality characteristics, economic success.

2. Teaching for entrepreneurship
   Typical characteristics: Students act, role play and pretend to be entrepreneurs.
   Typical contents: Generating ideas, team building, business planning, creativity, innovation, opportunity recognition.

3. Teaching through entrepreneurship
   Typical characteristics: Learning through and with real-life entrepreneurship, enable students to experience being entrepreneurs, pitching business ideas to investors and shareholders, teaching with real-life entrepreneurs.
   Typical contents: Person induced business simulations, incubators, internships, collaboration with real business people.

These three themes give a first orientation for the specific manifestations of the study program. According to Aronsson and Birch (2004), the third theme is the most promising way to teach entrepreneurship. This is underpinned by Rasmussen and Sørheim (2006). They conducted a study on action-based activities at five Swedish universities in the area of entrepreneurship education. They concluded that learning-by-doing is more suitable for entrepreneurship education rather than approaches focusing only on teaching. They also state that this type of education is better aligned with the economic goals of entrepreneurship education. They also show requirements and limitations and give concrete implications for entrepreneurship education practice. This is also supported by Hattie (2009) who specifies an effect size for problem-solving teaching with $d = 0.61$. Problem-solving or project-based design therefore is a direct implication for the specific manifestations of the study program design.
In addition to the project-based approach, there are also references in the literature to other areas of course design. Regarding knowledge transfer in lectures, the literature shows that the widespread approach to transfer content in the form of a monologue is not efficient. An alternative to this approach is the so-called Sandwich Principle developed by Wahl (2020). In this approach there is a systematic alternation between expert input and active engagement of the students with the content (Wahl, 2020). The overarching goals of this structure are increased attention and learning success, higher intrinsic motivation and competence experience as well as increased skill acquisition. Since these goals are important for the success of the study program, this didactical approach represents another building block for the specific manifestations of the study program.

There is also some evidence on the selection of suitable teachers. Matsekh-Ukayinskyy et al. (2020) stated that teachers for entrepreneurship education should have extensive experience in theory and practice in their subject area. Kuckertz (2013) also identifies these as promising for teaching entrepreneurship. A selection of teachers according to this description is another proposition for the design of the study program.

Industry 4.0 skills and education

After the consideration of literature regarding entrepreneurship education, the existing literature of I4 was analyzed. I4, often referred to as the “fourth industrial revolution”, is a term firstly used in 2011 by the German government to describe a project of its high-tech strategy (Capestro & Kinkel, 2020; Culot et al., 2020). The term describes a paradigm shift in smart and autonomous manufacturing and logistics (Bai et al., 2020). The term is discussed intensively and there are various definitions (Capestro & Kinkel, 2020; Culot et al., 2020). It is sometimes used as a synonym for smart manufacturing, smart factory, intelligent manufacturing systems (IMS), digital manufacturing or industrial Internet of things (IIoT) (Capestro & Kinkel, 2020; Jeschke et al., 2017). Also, the term I4 is described to be “an umbrella concept for a broad range of technologies and applications” (Culot et al., 2020, p. 10). Therefore, to reduce complexity, the presence of the following criteria is used to delineate I4: physical component, digital component and communication or intelligence component in the context of manufacturing or logistics (Bai et al., 2020; Koleva & Andreev, 2018).

Maisiri et al. (2019) conducted a literature review in which they compiled the necessary and essential skills for the engineering profession in I4. They have summarized their findings in requirements and divided them into different categories. The two main categories are “technical skills” and “non-technical skills/soft skills”. They divided the category “technical skills” in the sub-categories “technological skills”, “programming skills” and “digital skills”. Additionally, they divided the category of “non-technical skills/soft skills” into “thinking skills”, “personal skills” and “social skills.” All of the categories were divided further. They list a total of 37 skills that are essential for engineers for I4. Since the focus is on the technical skills, some essential skills are of particular importance for the requirements of the study program and are therefore highlighted:
• Application and use of technological skills
• Process digitalization and understanding
• Ability to work with the Internet of things, autonomous robots, 3D printing, and other advanced technologies

These skills are used as the basis for defining the propositions regarding I4. The division between technical and social skills is also applied by various other authors. Bongomin et al. (2020) conducted a literature review on this topic and came to the same conclusion that the necessary skills are broadly diversified and that the division between technical and social skills is beneficial. In addition to that, Popkova and Zmiyak (2019) conclude that social skills are of particular importance. Koleva and Andreev (2018) discuss that production managers need to have complex problem solving, critical thinking and creativity skills and therefore should utilize methods for innovation in management and decision making. There are also other works that deal with skills and competency models in the area of I4 teams, for example, the work of Marnewick and Marnewick (2020), Prifti et al. (2017) or Grzybowska and Łupicka (2017). These works also have a strong reference to soft skills such as personal and interpersonal skills, which must be considered. However, these areas will be covered very extensively by the findings from the field of entrepreneurship education, so that the focus here remains on the technical component.

In summary, it can be said that the technical component plays a significant role in the field of I4 and technical skills will therefore need to have an effect on the requirements and propositions. However, the literature review in this area shows that social skills also play an important role and must be considered accordingly.

Industry 4.0 entrepreneurship education

Since the study program specifically addresses the I4 domain, the literature in the particular interface of entrepreneurship education and I4 was also examined to determine what inferences can be drawn about the design of the study program.

Kruger and Steyn (2020) developed “a conceptual model of entrepreneurial competencies needed to utilize technologies of Industry 4.0”. The five dimensions of their model are: Innovation, creativity, business integration and technology skills, leadership and communication and networking and sales. Each dimension is further divided into eight to 25 sub dimensions or skills. The main focus of the model lays in technical skills required and the appropriate technical understanding of I4. They therefore follow the logic of three layers of I4 which consist of the physical layer, the connectivity layer and the digital layer. Even though their research also focuses on the precise interface between entrepreneurship and I4, their findings therefore cannot be used as a content specific basis for the study program.

Nhleko et al. (2022) conducted a study on the effect of I4 on entrepreneurship education with a focus on higher education institution. Their conclusion has an impact on the overall understanding of the study program. They recommend to integrate I4 into existing offerings of entrepreneurship education at higher education institutions to equip students with the necessary skills and competencies for their
future work life. This stresses the importance of the developed study program even more.

As could be seen in the literature review on entrepreneurship education in general, the offering focuses on “generic principles of identifying opportunities and taking action on them” (Mkwanazi & Mbohwa, 2018, p. 320). However, they also describe I4 as a new challenge to entrepreneurship. This is because of the “heightened dependence of viable business opportunities on technological, economic and social systems” (Mkwanazi & Mbohwa, 2018, p. 320). According to the authors, this is not adequately addressed in entrepreneurship education programs. They therefore recommend developing entrepreneurship education offerings that consider rapid change and advancements in technology, which needs to be considered in the design of the study program. As a field of future research, they particularly name the provision of entrepreneurship education which addresses I4 implications.

Through the literature review it became apparent that the understanding of entrepreneurship education as well as offerings specifically adapted to the field of I4 is rare and founders or teams in this field are not specifically trained in this sub-discipline. Therefore, this topic is investigated further in the field-based investigation.

**Entrepreneurial intention**

As an addition to the areas of entrepreneurship education and I4, particular importance lays on the positive influence on entrepreneurial behavior. Entrepreneurial intention (EI) is considered to be the best predictor of entrepreneurial behavior (Sabah, 2016). It therefore seems to be rational to design the study program in a way that makes it likely to increase entrepreneurial intention (EI) of the attendees. To do so, the theory of planned behavior (TPB) was used as a basis. The TPB is used quite extensively to explain and measure entrepreneurial intention (Sabah, 2016). Figure 1 gives an overview about the model and its mechanisms.

![Figure 1](image.png)

*Fig. 1 Model of the theory of planned behavior (TPB) according to Ajzen (1991)*
As can be seen in the model, intention is a central factor in the TPB (Ajzen, 1991). Intentions conclude the motivational factors. They indicate the willingness and effort to execute a planned behavior. Ajzen (1991) established the general rule that “the stronger the intention to engage in a behavior [is], the more likely should be its performance” (Ajzen, 1991, p. 180).

The intention is determined by three conceptually independent determinants. These are:

1. **Personal attitude towards the behavior (PA)**
   
   Personal evaluation of the behavior. Is the behavior favorable or unfavorable?

2. **Subjective Norm (SN)**
   
   Perceived social evaluation of the behavior. Is the behavior socially favorable or unfavorable?

3. **Perceived Behavioral Control (PBC)**
   
   Perceived ability of performing the ability. Is it easy or difficult to perform the behavior in question?

Since it is the goal of the study program to have a positive impact on the entrepreneurial behavior of the participants, the TPB and its sub-categories have implications on the design and the evaluation of the study program.

**Psychological characteristics linked to entrepreneurship**

As described before, Kuckertz (2021) defines character development as the third mission of entrepreneurship education and encourages educators to reflect on whether this goal is followed or not. This is the reason why psychological characteristics linked to entrepreneurship were considered. Following the structured analysis of Ferreira et al. (2012), internal locus of control (LoC), propensity to take risk (PtR), self-confidence (SC), need for achievement (NfA), tolerance of ambiguity (ToA) and innovativeness (INO) are the psychological characteristics that are mostly linked to entrepreneurship in literature. This is mostly based on the study of Koh (1996) who describes the items as follows:

1. **Innovativeness (INO)**
   
   Describes one’s ability of perceiving and acting on business activities in new and unique ways.
2. Locus of control (LoC)

Describes one’s interpretation about positive and negative experiences that one is encountering. While individuals with an internal locus of control believe that they can control what is happening, individuals with an external locus of control believe that the things that happen to them are the result of external factors (e.g., luck or fate).

3. Need for achievement (NfA)

Describes the level of one’s desire to be successful.

4. Propensity to risk (PtR)

Describes one’s orientation towards taking chances in uncertain decision-making contexts.

5. Self-confidence (SC)

Describes one’s believe to be able to achieve the goals that are set.

6. Tolerance of ambiguity (ToA)

Describes one’s manner in which a person perceives an ambiguous situation and organizes the available information to approach it.

Ferreira et al. (2012) examined that these characteristics do not necessarily have an impact on entrepreneurial intention (EI). However, since the goal here is not to increase entrepreneurial intention (EI) but to achieve the independent goal of character development, these categories will be used.

Field-based investigation

After the analysis of the literature, field-based investigation helped to further understand the context and specifics of the domain. This is a prerequisite for developing a tailored study program. Since there was little evidence on entrepreneurship in the field of I4, we conducted a study to develop a better understanding of the topic (Wahl & Münch, 2021). The study showed that there are essential characteristics in entrepreneurship in I4 that are fundamentally different from other domains. In this study we differentiated the essential characteristics in the following dimensions: business phases by Maurya (2012) (customer/problem fit, problem/solution fit, product/market fit, scaling/business model fit), skills and resources.

Based on this initial study, content areas were determined that need be considered as part of the knowledge transfer, as these are essential for I4 Startups. These content areas are:
• Specifics of I4 entrepreneurship
• Methods for I4 entrepreneurship
• Business model aspects (finance and sales) for I4 entrepreneurship

These content areas, like the other content areas that emerged from the literature review, are relevant to the design of the study program and are incorporated into the propositions.

The phase of analysis and exploration allowed to better understand the problem and to be able to narrow it down. It was also possible to define a broad and long-term goal for the study program. Through the literature review and the field-based investigation, it was possible to draw first conclusions on the requirements, propositions and specific manifestations of the study program.

Design and construction

After the scientific foundation was laid, the findings could be converted into a precise study program design. In order to arrive step by step at a fully elaborated design, a morphological chart is used in EDBR. This morphological chart leads in three steps from requirements, via propositions, to specific manifestations, of which the study program will finally consist. The findings of analysis and exploration were used to develop a morphological chart for the study program. The morphological chart can be derived from the findings of the analysis and exploration (see Table 1):

Setting

The construction of the study program underlies some general conditions, which result from embedding it in a university context. The course is offered at a German university of applied sciences and is creditable with 5 ECTS for selected courses of studies from the fields of business administration and computer science as an elective module. The course can also be taken for extra-curricular credit.

Due to the creditability with 5 ECTS, requirements must be met. One of these requirements is the workload, which is set at 150 hours. These need to be divided into 60 hours of attendance and 90 hours of self-study as specified by a faculty of the university. In addition, the creditability in several study programs and the possibility of extra-curricular participation make it necessary to conduct the block week not during the semester, but during the semester break. In addition to the organizational necessity, there is also some evidence on why this kind of format can be beneficial. Matsekh-Ukrayinskyy et al. (2020) concluded that there are advantages of short-term entrepreneurship study programs with a bootcamp character which are:
| Requirements                                                                 | Propositions                                                                 | Specific manifestations                                                                 |
|------------------------------------------------------------------------------|------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| **REQ1:** Impart relevant knowledge for a startup in the field of Industry 4.0 | P1: Impart relevant specifics of I4 entrepreneurship                          | M1: Lectures on relevant and I4 specific topics                                         |
|                                                                              | P2: Impart relevant technologies and processes of I4                         | M2: High practical relevance of lectures through active and interactive work phases during lectures |
|                                                                              | P3: Impart relevant methods for I4 entrepreneurship                          | M3: Knowledge transfer through inspiring lecturers from practice                        |
|                                                                              | P4: Impart relevant business model aspects of I4 startups (such as finance and sales) |                                                                                         |
|                                                                              | P5: Improve personal attitude towards behavior (PA)                           | M4: Visits to inspiring innovation centers and places                                   |
|                                                                              | P6: Improve subjective norm (SN)                                              | M5: Work on projects with practical relevance and under real conditions                 |
|                                                                              | P7: Improve perceived behavioral control (PBC)                               | M6: Work in interdisciplinary teams                                                    |
|                                                                              | P8: Increase the self-perceived level of innovativeness (INO)                | M7: Interim and final presentation with feedbacks and peering session                    |
|                                                                              | P9: Increase the self-perceived locus of control (LoC)                        | M8: Feedback sessions/coaching during the work phases                                   |
|                                                                              | P10: Increase the self-perceived need for achievement (NfA)                  |                                                                                         |
|                                                                              | P11: Increase the self-perceived propensity to risk (PtR)                     |                                                                                         |
|                                                                              | P12: Increase the self-perceived self-confidence (SC)                        |                                                                                         |
|                                                                              | P13: Increase the self-perceived tolerance of ambiguity (ToA)                |                                                                                         |
| **REQ2:** Improve the entrepreneurial intention for Industry 4.0 startups     | P5: Improve personal attitude towards behavior (PA)                           |                                                                                         |
|                                                                              | P6: Improve subjective norm (SN)                                              |                                                                                         |
|                                                                              | P7: Improve perceived behavioral control (PBC)                               |                                                                                         |
|                                                                              | P8: Increase the self-perceived level of innovativeness (INO)                |                                                                                         |
|                                                                              | P9: Increase the self-perceived locus of control (LoC)                        |                                                                                         |
|                                                                              | P10: Increase the self-perceived need for achievement (NfA)                  |                                                                                         |
|                                                                              | P11: Increase the self-perceived propensity to risk (PtR)                     |                                                                                         |
|                                                                              | P12: Increase the self-perceived self-confidence (SC)                        |                                                                                         |
|                                                                              | P13: Increase the self-perceived tolerance of ambiguity (ToA)                |                                                                                         |
| **REQ3:** Improve the psychological characteristics linked to entrepreneurship | P5: Improve personal attitude towards behavior (PA)                           |                                                                                         |
|                                                                              | P6: Improve subjective norm (SN)                                              |                                                                                         |
|                                                                              | P7: Improve perceived behavioral control (PBC)                               |                                                                                         |
|                                                                              | P8: Increase the self-perceived level of innovativeness (INO)                |                                                                                         |
|                                                                              | P9: Increase the self-perceived locus of control (LoC)                        |                                                                                         |
|                                                                              | P10: Increase the self-perceived need for achievement (NfA)                  |                                                                                         |
|                                                                              | P11: Increase the self-perceived propensity to risk (PtR)                     |                                                                                         |
|                                                                              | P12: Increase the self-perceived self-confidence (SC)                        |                                                                                         |
|                                                                              | P13: Increase the self-perceived tolerance of ambiguity (ToA)                |                                                                                         |
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• Reduced workload throughout the semester
• Early integration into academic and social life

Lectures and content

The lectures are designed and put together according to the findings from analysis and exploration and focus on imparting the described specifics of I4 entrepreneurship. The lectures were fitted into the one-week curriculum specified by the setting. The order of the lectures is determined by the phases that a startup goes through. Figure 2 provides an overview of the block week that is conducted at the beginning of the study program:

As can be seen in Fig. 2, the work phase is also already initiated during the block week. This is explained in detail in the part on project work.

In order to facilitate the transfer of the lectured contents into practice, the structure of the lectures follows the described sandwich principle (Wahl, 2020). This approach runs through all lectures and all lecturers have to commit themselves to stick to this approach in their lectures. The target of the course management was to integrate an interactive working part after 15 minutes of input at the latest. This measure was intended to make the transfer of knowledge as efficient as possible.

In addition to the content and the teaching method, special focus was also placed on the selection of the lecturers. They were selected to meet the criteria described by Matsekh-Ukrawynsky et al. (2020). Therefore, experts from the field who have several years of relevant professional experience in the area of I4 entrepreneurship were chosen as lecturers. These high-profile lecturers were also selected to inspire and motivate the students and to give the students the opportunity to build a powerful network in the startup scene. Table 2 gives a description of the lecturers:
In addition to the effects that should be achieved by the lecturers from practice, the students received insights into the local ecosystem through special formats. The goal was to inspire and motivate them further and to give them the opportunity to gain practical experience. Therefore, a “learning factory” for production and logistics was visited on campus, as well as a local innovation center. At both locations, use cases from the field of I4 were demonstrated and students could experience some of the technologies themselves. This gave the students the opportunity to experience the technologies in real-life use. In addition, both places represent innovation power and additionally showed the students the possibility to implement their ideas and projects.

Table 2  Overview about lecturers

| Lecture                                             | Background of lecturer                                                                 |
|-----------------------------------------------------|-----------------------------------------------------------------------------------------|
| Domain exploration: Technologies and processes of Industry 4.0 | PhD in Industry 4.0 related topic. Relevant experience in technology savvy projects with automotive and manufacturing industry partners |
| Lean startup for Industry 4.0                      | Multiple decades of automotive industry experience (head of global Innovation at an original equipment manufacturer (OEM)). Angel Investor, founder of an Industry 4.0 startup in the field of urban logistics. Book author and keynote speaker about innovation in logistics |
| Business modeling and Finance for Industry 4.0      | Former venture capital investor. Founder of a venture capital backed digital manufacturing knowledge startup |
| B2B and Enterprise sales for Industry 4.0           | Multiple years of experience in industry. Founder of a venture capital backed Industry 4.0 startup with around 100 employees (at the time of conducting the study program) |

In addition to the effects that should be achieved by the lecturers from practice, the students received insights into the local ecosystem through special formats. The goal was to inspire and motivate them further and to give them the opportunity to gain practical experience. Therefore, a “learning factory” for production and logistics was visited on campus, as well as a local innovation center. At both locations, use cases from the field of I4 were demonstrated and students could experience some of the technologies themselves. This gave the students the opportunity to experience the technologies in real-life use. In addition, both places represent innovation power and additionally showed the students the possibility to implement their ideas and projects.

Teaching through entrepreneurship

The described block week with its various components is part of an overarching concept. To follow the implications of the literature review the students had to work on startup ideas in interdisciplinary teams (Rasmussen & Sørheim, 2006; Sirelkhaim et al., 2015). This was to pursue various goals: On the one hand, the analysis has shown that interdisciplinary teams are an important factor for I4 startups. Therefore, the groups were put together by the course management. The criterion for this was exclusively the students’ degree program. In addition, the project was intended to teach the participants how to implement startup projects and meet the associated challenges in a setting that was as practical as possible. This should enable them to go beyond the mere transfer of knowledge to be able to build I4 startups. According to the TPB, the resulting confidence in one’s own abilities (perceived behavioral control (PBC)) should already lead to an increased intention to start such a company.

In order to make the project work possible, the overall concept had to be structured and adapted accordingly. The students should already prepare possible
problem fields from logistics and production before the block week. These problem areas were then presented and discussed within the groups in the designated phase on the first day of the block week. The students had to decide on one of the problem areas and go through a design thinking process with it, applying the knowledge they had learned in the course of the week. This direct application allowed the teams to apply initial methods and receive feedback on their project progress during the block week.

After the block week, in which the knowledge for the execution of the projects was to be imparted, the teams had a working phase of one month to transfer the learned knowledge into practice. The structure of a startup accelerator was applied: The course management was available to the teams as a kind of coach or mentor to get feedback on their project progress. The project progress was then presented in a bundled form at the end of the phase in a kind of interim sprint, the interim presentation, which was part of the grading. During this presentation, the teams received feedback from experts from the field.

The teams then had to incorporate this feedback in a second work phase and push their startup further. During this work phase, the teams again had the opportunity to obtain feedback. The current status of the project was then presented at the final presentation. This represents the second major part of the grading. There were no precisely defined requirements for the interim and final presentations. The individual progress of the team was assessed with a focus on problem and solution exploration. The assessment was carried out by experts from the field under real conditions, as if the teams were working on real startups. The final presentation also marks the end of the study program. Figure 3 shows the overall structure of the study program:

Execution, evaluation and reflection

The designed study program was conducted for the first time during the semester break before the 2021 winter semester. 25 students (male = 18, female = 7) participated in the study program. Of these, 21 were able to receive credit for the course as an elective module. The majority of the students came from courses in economics

Fig. 3 Overview of study program design
and business informatics. The reason for this is that the elective module was creditable in these courses. The students worked in six teams, which consisted of four to five people. In total, 100% of the students who attended the block week successfully completed the course.

Participants were asked about their individual previous experience. A distinction was made between previous experience in entrepreneurship, in I4, and in I4 entrepreneurship. Of the 22 students who participated in the evaluation, 17 had previous experience in the field of entrepreneurship. This corresponds to 77% of the participants. Nine (41%) stated that they already have experience in the area of I4. Only two students stated that they had also have experience in the specific area of I4 entrepreneurship. This corresponds to about 9% of the participants.

**Evaluation of knowledge:** In order to evaluate whether the study program is able to impart the knowledge relevant to the field of I4, knowledge items were evaluated and compared. Since there is no standardized questionnaire for I4 entrepreneurship, a self-developed questionnaire was used following the generally accepted principles of construction for theory-based knowledge tests (Lane et al., 2016). According to these principles, several steps were taken to guarantee content validity: First, the selection of content was supported by a literature review conducted by the author. Second, the results of the field-based investigation were used to narrow down the topics and highlight the most important areas of knowledge for the questionnaire. Third, an expert consultation was conducted to make the final choice of integrated items. Experts were defined as those lecturers who teach the individual modules within the study program. The test design contained 2 items that were intended to be representative of each of the 5 content areas taught. Review of the test design (distribution analysis, item analysis, goodness-of-fit criteria) is pending and will be integrated into upcoming runs of the study program as part of the iterative approach taken in EDBR.

For each of the areas, one multiple choice question and one open ended question were asked. For the open-ended questions, four answers were to be given in each case. The calculation logic was such that for multiple choice questions, each correct answer was awarded one point. One point was deducted for incorrect answers, so that negative scores were possible. In the case of the open-ended questions, one point was awarded for each correct answer, so that a minimum of zero points and a maximum of four points were possible. Because of the division into five dimensions of knowledge, a total of ten items was measured: Relevant specifics of I4 entrepreneurship (two items), relevant technologies and processes of I4 (two items), relevant methods and approaches for I4 entrepreneurship (two items) and relevant business model aspects of I4 startups (two items for finance and two items for sales). In the appendix the questions asked in the evaluation questionnaire are displayed.

**Evaluation of entrepreneurial intention:** For entrepreneurial intention, the questionnaire developed by Liñán and Chen (2009) was used. However, the questions were adjusted to the research question by including the dimension of I4. The questionnaire consists of 20 items, each measured with a Likert scale of one to seven, where one stands for “total disagreement” and seven for “total agreement.” The 20 items are divided among the different dimensions of the model: personal attitude towards the behavior (PA—five items), subjective norm (SN—three items),
perceived behavioral control (PBC—six items) and entrepreneurial intention (EI—six items).

**Evaluation of psychological characteristics:** For the area of psychological characteristics linked to entrepreneurship, the questionnaire developed by Koh (1996) was used. To minimize response-set bias, this questionnaire includes questions that are reverse-scored and intermingled with other statements (Koh, 1996). A Likert scale of one to seven was also used, analogous to the entrepreneurial intention questionnaire. The questionnaire includes 36 items divided into the following categories: Innovativeness (INO—five items), locus of control (LoC—seven items), need for achievement (NfA—six items), propensity to take risk (PtR—six items), self-confidence (SC—six items) and tolerance of ambiguity (ToA—six items).

Table 3 shows the different areas of evaluation:

The results of the evaluation were quantitatively analyzed using IBM SPSS by comparing the mean values before and after the study program by using either dependent T tests or Wilcoxon–Mann–Whitney Test (Mann & Whitney, 1947; Wilcoxon, 1945). Also, the effect size was calculated, analyzed and categorized according to Cohen (1988).

In addition to the quantitative evaluation, individual feedback from the students was also assessed and observations by the course instructor were used for insight generation. One point of criticism that both the course instructor noticed and several students mentioned was a lack of clarity about the structure of the course. Students assumed that the content taught had to be implemented immediately and that most of the projects should already be completed after the block week. During the lecture week, processing phases had been inserted into each lecture—according to the sandwich principle. These had the goal to deal with the teaching contents, to comprehend them and to understand them more deeply. However, some of the students were so focused on the realization of their own project ideas that they did not try to understand the information given, but instead concentrated on working on their own projects, which was not supposed to happen until the transfer phases. This impaired the effectiveness of knowledge absorption. If it had been clear to the students that they would have enough time in the transfer phases to realize their project ideas, they might have made better use of the processing phases during the lectures.

The projects results were satisfactory, measured on the utilization of the taught methods. All teams took an iterative approach to their projects and used relevant startup methodologies. All teams also integrated data points from interviews with real potential customers into their problem exploration. Some of the teams pivoted their problem and solution hypothesis multiple times because of the feedback from practice. The teams’ problem areas also coincided with the content taught. All teams dealt with practice-relevant topics from the field of I4.

In addition to that, some participants used the opportunity to give optional and unrestricted feedback on the course. Some of these feedbacks provide insight into the goal of the study program and is closely related to the quantitative analysis. For example, one student wrote “at the beginning, I was critical of an own startup, but the summer school made me want to do it.” This can be linked to entrepreneurial intention. For this particular student the study program did in fact lead to an increased motivation to start a company. Another
| Requirements (REQ)                                                                 | Propositions (P)                                                                 | Evaluation                                      |
|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|-------------------------------------------------|
| REQ1: Provide relevant knowledge for a startup in the field of Industry 4.0      | P1: Impart relevant specifics of I4 entrepreneurship                              | Self-developed multiple choice and open-ended questions |
|                                                                                   | P2: Impart relevant technologies and processes of I4                             |                                                 |
|                                                                                   | P3: Impart relevant methods for I4 entrepreneurship                               |                                                 |
|                                                                                   | P4: Impart relevant business model aspects of I4 startups (finance and sales)    |                                                 |
| REQ2: Improve the entrepreneurial intention (EI) for I4 startups                  | P5: Improve personal attitude towards behavior (PA)                               | Questionnaire developed by Liñán and Chen (2009)  |
|                                                                                   | P6: Improve subjective norm (SN)                                                 | Likert scale 1–7                                |
|                                                                                   | P7: Improve perceived behavioral control (PBC)                                   |                                                 |
| REQ3: Improve the psychological characteristics linked to entrepreneurship         | P8: Increase the self-perceived level of innovativeness (INO)                     | Questionnaire developed by Koh (1996)             |
|                                                                                   | P9: Increase the self-perceived locus of control (LoC)                            | Likert scale 1–7                                |
|                                                                                   | P10: Increase the self-perceived need for achievement (NfA)                      |                                                 |
|                                                                                   | P11: Increase the self-perceived propensity to risk (PtR)                         |                                                 |
|                                                                                   | P12: Increase the self-perceived self-confidence (SC)                            |                                                 |
|                                                                                   | P13: Increase the self-perceived tolerance of ambiguity (ToA)                    |                                                 |
participant wrote: “I also definitely outgrew myself in this subject and left my comfort zone. It wasn’t always easy, but it helped me incredibly in terms of my knowledge, but also personally. Before, I would never have thought I could delve so deeply into Industry 4.0 topics, and yet I succeeded through this subject”. This statement can be related to other goals of the study program such as knowledge impartment and perceived behavioral control (PBC) and underpins the conclusion from the data that the study program led to a significant change in this area.

Another suggestion for improvement that emerged from the reflection was the expansion of the course to other faculties and study programs. Although the course was open to all students, mainly students of business administration and computer science took part in the course due to the creditability. Based on theory, however, it makes sense to have interdisciplinary teams work on I4 startups. In order to make this possible, it is necessary to make the event creditable for other study courses as well.

Results

The results that were generated using the described methodological approach were analyzed according to the three dimensions knowledge, entrepreneurial intention and psychological characteristics linked to entrepreneurship and therefore will be displayed accordingly:

Knowledge

In the category of knowledge, the goal was to measure if the participants of the study program increased their knowledge in the relevant areas. To analyze the data correctly there are some things that need to be considered: The maximum of achievable points varies from question to question. While all of the open-ended questions have a maximum of four achievable points, the multiple-choice questions vary from one to three possible points and it is also possible to achieve negative scores. This is why there are also negative means (for C1 Pre, C1 Post and C7 Post). It can be seen that some of the values have improved as desired, while others have not. Some of the values have even decreased. Additionally, there are some items for which almost the maximum value could be achieved (e.g., C3 Post or C8 Post) while for other items the difference between achieved and possible points is bigger (e.g., C1 or C10). Table 4 shows mean values before and after the study program:

The normality of the items was analyzed using the Kolmogorov–Smirnoff Test (Massey, 1951). The threshold for normal distribution is $p = 0.05$. Since the majority of the ten items are not normally distributed (two items $p \leq 0.084$; eight items $p \leq 0.027$), the comparison of means has to be computed using nonparametric Wilcoxon–Mann–Whitney Test (Mann & Whitney, 1947; Wilcoxon, 1945). Table 5 shows the results of this test and the calculation of Cohen’s $d$ (Cohen, 1988) to determine the effect size:
Comparing knowledge before and after the training revealed significant increases \((p < 0.05)\) in the areas of relevant methods for I4 entrepreneurship (items C5; \(Z = 2.045; p = 0.041\) and C6; \(Z = 3.458; p = 0.01\)), finance for I4 entrepreneurship
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(items C8; \(Z = 3.297; p = 0.001\)) and sales for I4 entrepreneurship (items C9; \(Z = 2.037; p = 0.042\) and C10; \(Z = 2.541; p = 0.011\)). The effect size (Cohen, 1988) of these changes was intermediate for C5 \((d = 0.436)\), C9 \((d = 0.434)\) and C10 \((d = 0.542)\) and strong for C6 \((d = 0.737)\) and C8 \((d = 0.703)\).

There are changes in the other areas as well. The majority of them increased while there are also values that decreased. However, the other items did not show significant changes so that it can be stated that knowledge in the other areas did not significantly change after the study program \((p \geq 0.132)\).

### Table 6

| Category | Mean (scale 1–7) | SD | SE mean |
|----------|------------------|----|---------|
| PA pre   | 4.300            | 1.161 | 0.247   |
| PA post  | 4.164            | 1.237 | 0.264   |
| SN pre   | 5.106            | 1.351 | 0.288   |
| SN post  | 4.924            | 1.028 | 0.219   |
| PBC pre  | 2.197            | 1.076 | 0.229   |
| PBC post | 3.750            | 1.146 | 0.244   |
| EI pre   | 2.841            | 1.367 | 0.291   |
| EI post  | 3.417            | 1.445 | 0.308   |

### Table 7

| Category | Change in mean | SD | SE mean | \(t\) | Sig. (2-tailed)/\(p\) | Cohen’s \(d\) |
|----------|----------------|----|---------|-------|----------------------|---------------|
| PA       | -0.136         | 1.483 | 0.316   | -0.431 | 0.671                | -0.092        |
| SN       | -0.182         | 1.586 | 0.338   | -0.538 | 0.596                | -0.115        |
| PBC      | 1.553          | 1.285 | 0.274   | 5.668  | 0.000                | 1.208         |
| EI       | 0.576          | 1.993 | 0.425   | 1.355  | 0.190                | 0.289         |

Entrepreneurial intention

The goal regarding entrepreneurial intention was to improve the three predictors for entrepreneurial intention and entrepreneurial intention in the field of I4 itself. The respective mean values were used to summarize the items to the respective category. The values of the Cronbach coefficient (Cronbach, 1951) indicate high consistency \((\alpha(PA)=0.904; \alpha(SN)=0.789; \alpha(PBC)=0.943; \alpha(EI)=0.975)\) so that this is statistically valid. Table 6 shows the values that were measured for the items before and after the study program:

Analyzing the values before the study program it can be stated that the attendees already think of I4 entrepreneurship as a potential career path (personal attitude towards the behavior \((PA)=4.300)\) and also think that their surrounding is in favor of them becoming I4 entrepreneurs (subjective norm \((SN)=5.106)).
However, the values of perceived behavioral control (\(PBC = 2.197\)) and entrepreneurial intention (\(EI = 2.841\)) are lower. This means that the participants do not think they are able to run an I4 startup and also do not have the intention of becoming I4 entrepreneurs.

Since it was the goal to improve these values, the mean values before and after the study program and also the effect sizes of the change were analyzed. The values of the entrepreneurial intention (EI) items are normally distributed (\(p \geq 0.130\)). Therefore, a T Test was computed. Table 7 shows the results of the T test:

Comparing the categories of entrepreneurial intention (EI), a significant improvement of perceived behavioral control (PBC) was revealed (\(t = 5.668; p = 0.000\)). The results improved by 1.533 (SD = 1.285) from 2.197 (SD = 1.076) to 3.750 (SD = 1.146). According to Cohen (1988) this is classified as a strong effect (\(d = 1.208\)). In addition to that, entrepreneurial intention (EI) also shows an improvement. However, this change is not significant (\(p = 0.190\)).

For personal attitude (PA) and subjective norm (SN) the values decreased. However, this change is also not significant (\(p \geq 0.596\)).

Figure 4 shows the changes in the three dimensions that determine entrepreneurial intention (EI) and also the value for the item of entrepreneurial intention (EI) itself:

According to the TPB, perceived behavioral control (PBC) indicates how far someone feels capable of achieving something (Ajzen, 1991). Since the values of this item increased significantly and the effect is strong, it can be assumed that the study program improved the students’ perceived behavioral control (PBC) of starting and running a I4 company. Although the level of entrepreneurial intention (EI) also changed, this change was not significant. The study program did not have a significant effect on personal attitude (PA) and subjective norm (SN). This means that the participants of the study program do not find an entrepreneurial

![Fig. 4 Changes in personal attitude (PA), subjective norm (SN), perceived behavioral control (PBC) and entrepreneurial intention (EI)](image-url)
career in I4 more appealing than before or that they think that a career in I4 entrepreneurship is socially more favorable than before.

**Psychological characteristics linked to entrepreneurship**

The third goal of the study program was to improve the psychological characteristics linked to entrepreneurship. The respective mean values were used to summarize the items to the respective category. However, the Cronbach Alphas of the items show poor internal consistency ($\alpha_{INO} = 0.610$; $\alpha_{LoC} = 0.648$; $\alpha_{NfA} = 0.541$; $\alpha_{PtR} = 0.458$; $\alpha_{SC} = 0.379$; $\alpha_{ToA} = 0.232$). The questionnaire was also used by Dinis et al. (2013). They also reported insufficient internal consistency ($\alpha_{INO} = 0.47$; $\alpha_{LoC} = 0.65$; $\alpha_{NfA} = 0.56$; $\alpha_{PtR} = 0.58$; $\alpha_{SC} = 0.39$; $\alpha_{ToA} = 0.31$).

Table 8 shows the descriptive statistics of the analysis of the psychological characteristics linked to entrepreneurship:

| Category | Mean (scale 1–7) | SD   | SE mean |
|----------|------------------|------|---------|
| INO pre  | 4.900            | 0.832| 0.177   |
| INO post | 4.964            | 0.692| 0.147   |
| LoC pre  | 4.279            | 0.873| 0.186   |
| LoC post | 4.435            | 0.889| 0.190   |
| NfA pre  | 4.780            | 0.789| 0.168   |
| NfA post | 4.720            | 0.786| 0.168   |
| PtR pre  | 3.856            | 0.838| 0.179   |
| PtR post | 3.773            | 0.714| 0.152   |
| SC pre   | 4.667            | 1.145| 0.244   |
| SC post  | 4.545            | 0.870| 0.186   |
| ToA pre  | 3.598            | 0.719| 0.153   |
| ToA post | 3.818            | 0.636| 0.136   |

Table 9 shows the comparison of mean values and effect sizes for psychological characteristics linked to entrepreneurship:

| Category | Change in mean | SD    | SE mean | $t$   | Sig. (2-tailed)/$p$ | Cohen’s $d$ |
|----------|----------------|-------|---------|-------|---------------------|-------------|
| INO      | 0.064          | 1.139 | 0.243   | 0.262 | 0.796               | 0.056       |
| LoC      | 0.156          | 1.135 | 0.242   | 0.644 | 0.527               | 0.137       |
| NfA      | -0.061         | 1.256 | 0.268   | -0.226| 0.823               | -0.048      |
| PtR      | -0.083         | 0.996 | 0.212   | -0.393| 0.699               | -0.084      |
| SC       | -0.121         | 1.401 | 0.299   | -0.406| 0.689               | -0.087      |
| ToA      | 0.220          | 0.855 | 0.182   | 1.205 | 0.242               | 0.257       |
there are as well values that increased but also values that decreased after the study program. To analyze if there are significant changes, a comparison of mean values was conducted. Since the values of the psychological characteristic items were normally distributed ($p \geq 0.057$), a $T$ Test was computed. Table 9 shows the values of this test:

The results show that the study program had no significant effect on any of the categories ($p \geq 0.242$).

**Conclusion and discussion**

The aim of the present study was to design, initial conduct and evaluate a study program tailored to the characteristics of I4 entrepreneurship based on the research questions. In the following, it will be shown how the research questions can be answered considering the present results:

*RQ1: What are the requirements for a study program in the field of I4 entrepreneurship?*

Due to the special characteristics of entrepreneurship in the area of I4, there are also special requirements for the design of a study program in this area. In particular, the knowledge to be imparted differs from generalist entrepreneurship courses. The relevant knowledge to be imparted includes: relevant specifics of I4 entrepreneurship, technologies and processes of I4, relevant methods for I4 entrepreneurship and relevant business model aspects of I4 startups.

*RQ2: How can this study program be designed to meet the defined requirements?*

The goal of the study program was to significantly improve the three target areas, which are: 1. knowledge, 2. entrepreneurial intention and 3. psychological characteristics. Since the requirement of positively influencing the psychological characteristics was not met, a statement can only be made for the first two areas. The present study program has shown relevant design aspects that have contributed to a significant increase in knowledge and perceived behavioral control (PBC). These aspects are: lectures on relevant topics, active and interactive work phases during lectures, inspiring lecturers from practice, visits to innovation centers and places, work on projects with practical relevance and under real conditions, interdisciplinary teams, presentations with feedbacks and peering session, and feedback sessions/coaching during the work phases.

*RQ3: How can the designed study program be evaluated?*

The present study program was evaluated based on various instruments. Data was collected using a pretest–posttest-design. Knowledge was evaluated by means of a knowledge questionnaire. For the evaluation of entrepreneurial intention, the theory of planned behavior and the according questionnaire developed by Liñán and Chen (2009) was used and adjusted to I4. For the psychological characteristics, a model of psychological characteristics linked to entrepreneurship and the according questionnaire developed by Koh (1996) was used.

There are further means to evaluate the designed study program. Examples are presented in the discussion of the threats to validity below. According to the iterative
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approach of EDBR, the presented optimization approaches regarding evaluation will be respected for the next run of the study program.

**RQ4: To what extent does the designed study program meet the requirements?**

Considering the study context and the limited external validity of the study, the evaluation shows that the study program was able to significantly improve some, but not all areas of knowledge. Even though the majority of the items improved, there are only a few of them that improved significantly. There are also items that didn’t change at all and even items that got worse, even though these changes weren’t significant either. That means that the goal to impart knowledge in the relevant areas of I4 could only be achieved to a certain extent. The question of why some of the imparted knowledge areas resulted in significant improvement, whereas other areas did not show significant change is critical to improving the study program. All lectures had both the same framework and the same structural design. It is therefore unlikely that these elements led to the changes. Similarly, there is also no discernible trend in terms of practical relevance, as all lectures were strongly practice-oriented and were held by lecturers from the field. Moreover, the imparted knowledge of all lectures was also transferred into practice through the problem-solving approach.

It is therefore reasonable to conclude that the content taught itself makes the difference. It should be noted here that the measurement instrument for the imparted knowledge has only two items per area and thus can only measure small aspects of the imparted knowledge. It is therefore possible that the accuracy of fit between the knowledge imparted and the item leads to the different results and that therefore the construcational validity of the instrument is low.

In order to improve the study program in terms of imparted knowledge, the measurement instrument should therefore be reviewed. To increase the accuracy of fit, additional methods can be applied. In order to test this hypothesis and to improve the course in this respect, constructive alignment can be used. This approach is used to ensure a high degree of alignment between the objectives of a course and the corresponding assessment criteria (Biggs, 1996). Consistent application of this approach could improve the quality of the measurement instrument by increasing the fit to the content of the course.

In addition, also other factors may have led to the fact that some areas did not improve significantly. In order to test this hypothesis, a more in-depth analysis of the lectures must be carried out.

Again, considering the study context and the limited external validity of the study, the study program was able to significantly improve perceived behavioral control (PBC) while subjective norm (SN), personal attitude (PA) and entrepreneurial intention (EI) itself were not influenced significantly. The main reason for the significant influence on perceived behavioral control (PBC) cannot be concluded from the data. However, it could be mainly due to the problem-solving approach and the project work that took a large part of the whole study program. The students learned in this structural element that they can develop their project independently and make entrepreneurial decisions that are beneficial for the success of the project on their own. This could have led to the fact that they feel more confident in doing so in general.

Even though personal attitude (PA) and subjective norm (SN) were not improved significantly, structural elements were included to increase these areas. By exposing
the students to the practical environment in which I4 startups work, the attractiveness of this career path was tried to improve. In addition, the lecturers from the field should help the students to build up their network and learn from people that think of I4 entrepreneurship as an attractive career option. The numbers show, however, that this was not the case. To improve the study program regarding personal attitude (PA) and subjective norm (SN), further analysis is necessary to determine how these factors can be improved. By that, existing structural elements can be improved or new elements can be integrated into the study program.

Since the three factors (PA, SN and PBC) are predictors of entrepreneurial intention (EI) according to the model (Ajzen, 1991), it is striking that perceived behavioral control (PBC) increases significantly, but entrepreneurial intention (EI) does not. This leads to the conclusion that entrepreneurial intention (EI) did not increase significantly because of the quite constant values of personal attitude (PN) and subjective norm (SN) or that the prediction of entrepreneurial intention (EI) is not linear to the three areas. A detailed investigation of the model’s interrelationships could shed further light on this.

The study program was not able to change the students’ psychological characteristics and therefore couldn’t fulfill the “third mission” of entrepreneurship. Here, context and limited validity can certainly play a role, so a definitive statement cannot be made. To determine why the study program was not able to significantly change any of the psychological characteristics, further analysis is necessary.

When discussing the results, the low internal consistencies should be mentioned. In the initial study by Koh (1996), the internal consistencies are not reported. However, in the present study as well as in a comparable study (Dinis et al., 2013), they appeared very clearly and thus do not fulfill Cronbach’s (Cronbach, 1951) criteria. Therefore, it seems rational to analyze other frameworks and measurement instruments and integrate them into the design of the study program and also into the evaluation approach.

**Limitations and future research**

Our results are subject to some threats to validity. To determine these threats to validity we used structure proposed by Wohlin et al. (2012), which we discuss in the following.

*Construct validity.* Construct validity depends on the measurement instruments used in each case. The questionnaire for measuring knowledge was developed following the generally accepted principles of construction for theory-based knowledge tests. Assessment of qualitative criteria (e.g., distribution analysis, item analysis, goodness-of-fit criteria) still has to follow. The entrepreneurial intention questionnaire has been extensively studied and scientifically validated. Construct validity of this measurement instrument can therefore be assumed. Koh’s questionnaire has shown low internal consistency. The construct validity of Koh’s questionnaire is therefore questionable.

*Internal validity.* The internal validity of the study is given by the quasi-experimental design, but the validity could be increased by the use of a control group. This
could exclude alternative factors that could influence the participants in the time of the study program. In the present study, it was not possible to use a control group.

**External validity.** The study program had to be adapted to the framework conditions of the university. This means that the time was limited to a few months which led to the fact that only these structural elements could be integrated that were compatible with this timeframe. In addition, there was also a limited sample of 26 participants of which only 22 participated in the pretest–posttest-evaluation. All the participants were studying at a university in Germany. The sample should be expanded quantitatively and qualitatively to be able to retrieve more representative conclusions. We also described the study program in such detail that it can be replicated and tested on external validity.

**Conclusion validity:** The conclusions were drawn from a rather small sample size. Nevertheless, we tried to give a first assessment of the impact of the study program. Additionally, the study program was conducted in the exact same setting for which it was designed and in which it has to show effects in the future.

The evaluation of the study program itself revealed potential fields of future research. There are threats to validity that could be addressed to make a more robust statement about the effect of the program. For instance, the questionnaire for measuring knowledge could be analyzed with regard to qualitative criteria (e.g., distribution analysis, item analysis, goodness-of-fit criteria) and the performance of the participants could be considered. This could help to better understand why the study program did not have the same effect on all the content areas. Constructive alignment could be a potential approach to increase the quality and evaluation of the study program. Additionally, further analysis of the lectures could help to understand why some of the imparted knowledge areas did not improve significantly and therefore to make improvements in design possible. The same applies for the TPB which was used as a basis for measuring entrepreneurial intention (EI). To fully understand why the areas of personal attitude (PA), subjective norm (SN) and entrepreneurial intention (EI) did not change significantly, while perceived behavioral control (PBC) did, further analysis could be helpful. Additionally, the interdependencies in the model should be analyzed to make valid statements about the predictive capacities of the model for I4. The evaluation of psychological characteristics should be investigated further since there were no significant changes even though it was one of the requirements of the study program. Additionally, the used questionnaire showed poor internal consistency which leads to the necessity of including other measurement instruments in the future.

Another area of future research can be seen in the development of a viable competency model of I4 entrepreneurship. Such a competency model could be used to improve the design of the study program by including a competency-based approach. The model could also be used to adjust and subsequently evaluate the study program.

**Summary**

In this study, the research gap in entrepreneurship education and I4 was taken as an opportunity to develop a study program for this particular domain. The educational design-based research (EDBR) approach was taken as a basis to analyze and define
the research questions, requirements and goals of the domain. Based on this, a study program focusing on content, teaching concept, project-based approach and other key elements was created. This study program was implemented and evaluated for the first time. The evaluation is based on the areas of 1. Knowledge 2. entrepreneurial intention for I4 and 3. psychological characteristics linked to entrepreneurship. The evaluation showed that some of the objectives could already be achieved. In particular, the area of perceived behavioral control (PBC) increased significantly. Other areas, such as the psychological characteristics, on the other hand, could not yet be significantly influenced. The results of this study will be used to improve the course. With an improved design and adapted components, the course will be conducted and evaluated again. This marks the beginning of a continuous improvement process of the course.

The study identified a number of interesting research questions for future research. These include what a competency model for entrepreneurship in I4 looks like, what the effects of the individual components of the study program are, how the individual components of the study program interact, and how the design of the study program can be improved. Also of interest is the question of what opportunities exist to influence psychological characteristics or how to better identify appropriate talents for such programs. Based on the assumption that the amount of talent is far from being tapped and that talent is not only found in innovation hotspots, programs like the one presented in this article could have great potential.

**Appendix**

| Item | Category | Type | Question                                                                 | Possible answers (for multiple choice) | Maximum of achievable points |
|------|----------|------|--------------------------------------------------------------------------|----------------------------------------|------------------------------|
| C1   | Relevant specifics of I4 entrepreneurship | Multiple Choice | In which phase do most Industry 4.0 startups fail? Please choose one or multiple answers | × Customer/Problem Fit × Problem/Solution Fit ✓ Product/Market Fit × Scale | 1                             |
| C2   | Open ended | | Please name four differences of startups in the field of Industry 4.0 in comparison to startups in other domains | | 4                             |
| Item | Category | Type | Question | Possible answers (for multiple choice) | Maximum of achievable points |
|------|----------|------|----------|---------------------------------------|-----------------------------|
| C3   | Relevant technologies and processes of I4 | Multiple Choice | Why is Industry 4.0 called Industry 4.0? Please choose one or multiple answers | ✓ Referring to industrial revolutions (fourth industrial revolution)  
× Consisting of four different components (hardware, software, sensors and data)  
× Including sensors and data of four dimensions  
× Referring to the next stage of Web 2.0 | 1 |
| C4   | Open ended | Please name four Industry 4.0 use cases | 4 |
| C5   | Relevant methods and approaches for I4 entrepreneurship | Multiple Choice | Why is product development difficult for Industry 4.0? Please choose one or multiple answers | ✓ Difficulty to get customer insights  
✓ Long development cycles  
✓ Difficult to find relevant use cases  
× Technical feasibility is often not possible | 3 |
| C6   | Open ended | Name four startup methods that can be applied for Industry 4.0 startups | 4 |
| C7   | Relevant business model aspects of I4 startups—Finance | Multiple Choice | Why can it be difficult for a startup in Industry 4.0 to find a venture capital firm to invest into their startup? Please choose one or multiple answers | ✓ Difficulty to scale business model  
× High fixed cost  
✓ High variable cost  
× Competitive market | 2 |
| C8   | Open ended | Which are the four most important aspects because of which venture capital firms make their investment decisions | 4 |
### Item C9

**Category:** Relevant business model aspects of I4 startups—Sales

**Type:** Multiple Choice

**Question:** Which specifics does sales for Industry 4.0 have in comparison to other domains? Please choose one or multiple answers

- ✓ Complex organizations and hierarchies to deal with
- ✓ Difficulty to find the right contact person
- × Customers are not willing to pay for pilot projects
- ✓ High quality standards and norms

**Maximum of achievable points:** 3

### Item C10

**Category:** Open ended

**Type:** Open ended

**Question:** Please name four benefits of using a sales funnel for Industry 4.0 sales

**Possible answers:**

- ✓ Sales
- ✓ High quality standards and norms
- ✓ Complexity of sales processes
- ✓ High demand for products

**Maximum of achievable points:** 4

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**Conflict of interest** The authors declare that they have no conflict of interest.

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